Analysis and Mitigation of Mechanical Shock Effects on High Speed Planing Boats

by

Sean D. Kearns

B.S. Mechanical Engineering - Boston University, 1994

Submitted to the Departments of Ocean Engineering and Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degrees of

Master of Science in Naval Architecture and Marine Engineering

and

Master of Science in Mechanical Engineering

at the
Massachusetts Institute of Technology
September 2001

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Abstract

United States Special Forces use high-speed planing boats in the performance of their missions. Operation of these boats, particularly in rough seas, exposes the occupants to severe mechanical shock exposure that has been linked to significant increase in the rates of acute and chronic injury. While many government and civilian organizations have researched various aspects of this problem over the past decade or more, no effective solution has yet been implemented in the fleet. In response to this problem, the Commander Naval Special Warfare Command in San Diego, CA forwarded a request to MIT's Ocean Engineering Department calling for a study of the problem. The object of this thesis is to conduct a comprehensive analysis of the problem, to research methods by which the problem can be mitigated, and to develop and validate a method for laboratory design, test, and evaluation, of shock mitigation systems.

First, a theoretical and empirical study is conducted of the hydrodynamic interaction between a boat's hull and the seaway, and how this interaction results in the generation of mechanical shock. Actual acceleration data is obtained from the boats while underway in typical operating conditions, and other similar data is obtained from previous studies.

Second, the mechanisms by which exposure to mechanical shock and vibration causes acute and chronic injury are investigated. Past human and animal testing is reviewed, along with information on the transmissibility and mechanical impedance of the human body. Information of this type, along with other injury data compilation studies, have contributed to existing injury prediction.

Third, a study and is made of the methods by which mechanical shock exposure on high-speed boats can be mitigated. Interfaces (e.g.- hull-seaway) are identified where shock mitigation can be achieved, and existing or conceptual shock mitigation systems are discussed. Additionally, operational methods (such as training) of reducing shock exposure effects are discussed.

Finally, a laboratory drop table apparatus is fabricated for use in the design, test and evaluation of shock mitigation systems. This test apparatus is validated by successful reproduction of shock events such as those experienced on high-speed boats, as well as by excellent repeatability and controllability.

Thesis Supervisor: J. Kim Vandiver
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This work is dedicated
to the memory of my mother

Carolyn Anne Kearns

The example she set in her life continues to be
the standard by which I judge my own.

Acknowledgements

First I want to thank Commander Randy Large of Naval Special Warfare Command in San Diego, CA. CDR Large introduced me to this problem, empowered me to investigate it in the manner I chose, and lent me advice and encouragement throughout the process. I would also like to extend thanks to Commander Peter Oswald, who was serving as the executive officer of Special Boat Unit 12 when I began this project. His commitment to solving this problem was both humbling and inspiring. To the officers and crews of the Special Boat Units who continue to operate these boats at the risk of injury to themselves, I offer my heartfelt thanks. Your support and cooperation during the many data recording trips (as well as your candid responses to my many questions) were vital in helping me understand this problem.

In a technical undertaking such as this one, help and assistance from experts in the field is crucial in order to make any progress. Dr. Ronald Peterson of Naval Coastal Systems Station in Panama City, Florida has been working on some aspect of this problem for the past 10 years. In Ron I found a researcher who, like myself, was intent on not merely researching the problem but solving it. His vast experience in this field was invaluable to me, as was his patience and grace over the past year as I hounded him relentlessly with countless phone calls and emails full of questions.

Special thanks go out to my father, David Kearns, who has been a source of unflagging support and enthusiasm during this effort. My work in the lab during the latter stages of this project would not have been possible without his help. I could never hope to find a better lab assistant and co-conspirator.

Most importantly, I thank my wife Tricia. Without her support and patience none of this would have been possible.

Chapter 1

1.0 Introduction

1.1 Motivation

United States Naval Special Forces play a significant role in maintaining national presence and security around the globe. The Special Warfare Community is a great force multiplier, offering a wide range of capabilities with relatively small amounts of manpower and machinery. The most critical pieces of the special warfare system are its personnel. Special warfare personnel are intelligent, highly trained, and highly motivated. Their mission effectiveness relies heavily on their superb physical and mental conditioning and the proper operation of their equipment. Many of the Navy's Special warfare missions utilize High Speed Planing Boats (HSPBs) both as operations platforms and for rapid insertion of personnel into mission areas. Emphasis on mission completion means that Special warfare personnel and equipment are frequently required to operate HSPBs at high speeds in rough seas. The combination of high speeds and rough seas subjects personnel and equipment to significant mechanical shock due to wave slamming and hull water entry. This mechanical shock exposure causes both acute and chronic injury to personnel as well as damage to equipment. The net result of this shock environment is a reduction in mission capability and effectiveness in the short term and the potential for permanent injury or disability to personnel in the long term.

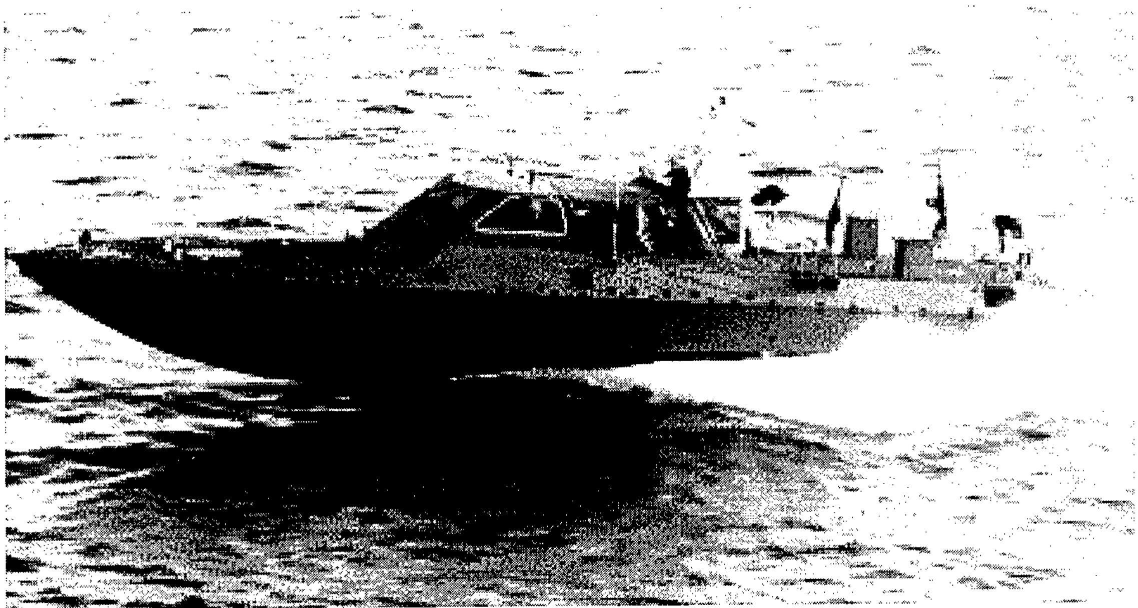
Currently, no system or design for shock mitigation exists aboard Navy Special warfare boats. The motivations for analyzing and eliminating this mechanical shock exposure problem range from the obvious goals of improved mission performance and reduced equipment and medical costs, to the more intangible factors such as personnel welfare, confidence, morale and the impact on future recruiting.

1.2 Background

The Navy Special Warfare community uses several different types of high-speed planing boats, depending on the mission requirements. This study focused on the two boat types used most often by the Navy's Special Boat Units: (1) the Naval Special Warfare Rigid-Hulled Inflatable Boat (NSW RIB), and (2) the MkV Special Operations Craft (MkV SOC). These two types of craft are used extensively by Special warfare in littoral and open ocean operations, and are representative of the range of boats used by Special warfare. Figures 1-1 and 1-2 show views of The MkV SOC and the NSW RHIB and give some of their specifications. Both craft are capable of quite high speeds and carry relatively large numbers of crew and passengers (SEALs) given their size. High-speed operations, combined with the factors of boat design/size and ocean waves, result in an adverse mechanical shock environment for the personnel and equipment aboard.

The Navy and the boating industry as a whole have long known of the potential for acute injury to personnel operating high-speed boats in relatively rough seas. Even low speed operations of these boats can result in serious injury due to the violent manner in which the boats respond to the seas. These acute injuries were not seen as endemic within the Special warfare community, and efforts to minimize them were mostly in the area of operational doctrine and physical conditioning. There seems to be no indication that significant chronic injury effects from these boats were known or even suspected until the 1990's.

In 1995, the Navy created a new enlisted rating, the Special Warfare Combat Crewman (SWCC), in response to an identified need for improved continuity and experience among its small boat operators. SWCCs work as boat drivers and crewman within the Special Boat Unit community throughout their entire naval career. This long-term service in the SBUs results in an excellent level of expertise, training and readiness among the boat crews, which translates to better overall mission effectiveness... exactly what the SWCC rating was intended to do.



(Photo obtained from **http://www.boats.dt.navy.mil/pg2/MK5.htm)**

Specifications:

Builder:	**Halter Marine Inc.**	Fuel Capacity:	**2600 gal**
Length:	**82 ft**	Max Speed:	**50+ kts**
Beam:	**17.5 ft**	Range:	**500+ nm**
Draft:	**5 ft (off plane)**		
Displacement:	**57+ tons**	Crew:	**5**
Hull:	**Aluminum Mono hull**	Passengers:	**16**
Propulsion:	**Diesel-Waterjet (4570 Hp)**	Variable	**6500 lbs**

FIGURE 1-1: MKV SPECIAL OPERATIONS CRAFT (MKV SOC)

(Photo obtained from **http://www.fas.org/man/dod-101/sys/ship/rhib.htm)**

Specifications:

Builder:		Fuel Capacity:	
Length:	**35 ft 11 in**	Max Speed:	**40+ kts**
Beam:	**10 ft 7 in**	Range:	**200+ nm**
Draft:	**2 ft 11 in (off plane)**		
Displacement:	**17,400 lbs**	Crew:	**3**
Hull:	**Composite monohull**	Passengers:	**8**
Propulsion:	**Diesel-Waterjet (~750 Hp)**	Variable	

FIGURE 1-2: NAVAL SPECIAL WARFARE RIGID-HULLED INFLATABLE BOAT (NSW RIB)

However, the inception of the SWCC rating in the Navy also brought with it an unexpected result, strong evidence of chronic injury effects from long-term HSPB operations.

Anecdotal information about significant acute and chronic injury rates among SWCCs has been available for several years, but no definitive study had been done to establish a true causal relationship between the two. In 1998 and on into 1999, the Naval Health Research Center (NHRC) conducted an injury compilation study of 201 SWCCs from SBU-12, SBU-20 and SBU-22. During the study, mission logs were reviewed to document new injuries resulting from specific boat operations and all 201 SWCCs were surveyed to obtain historical documentation of previous boat related injuries and contributing factors. The surveys consisted of self-reported injuries along with the circumstances leading up to the injury and any previous injury history, which may have contributed to the injury event. Figure 1-3 shows a summary of the vital statistics for the SWCCs involved in the report.

NHRC Report - SWCC Vital Statistics

	SBU 12	SBU 20	SBU 22	Total
Number	83	43	28	154
Age	32.2 ± 6.1	33.3 ± 4.7	29.5 ± 6.0[2]	32.0 ± 5.9
Stature (in)	70.6 ± 2.8	70.5 ± 2.8	71.4 ± 2.4	70.7 ± 2.7
Weight (lb)	186.1 ± 21.8	186.3 ± 23.7	195.1 ± 22.8	187.8 ± 22.7
BMI ($kg \cdot m^{-2}$)	26.3 ± 2.5	26.4 ± 2.5	27.0 ± 2.8	26.4 ± 2.5
Years in Military	11.7 ± 5.7	13.8 ± 4.7	10.0 ± 5.1[3]	12.0 ± 5.5
Years in SBU	4.5 ± 3.2	5.1 ± 2.7	4.7 ± 2.9	4.7 ± 3.0

[1] Values shown are means ± std. dev.
[2] Differs significantly ($P < 0.05$) from SBU 12 and SBU 20 values.
[3] Differs significantly ($P < 0.05$) from SBU 20 value.

FIGURE 1-3: NHRC INJURY COMPILATION - SWCC VITAL STATISTICS (PRUSACZYK, 2000)

Over the course of the NHRC study, 140 total injury events were reported. The majority of these injuries involved the straining or spraining of muscles and joints, with the remainder of the injuries including fractures, arthritis, dislocations, chronic pain, and others. An indication of where the forces mechanical shock are causing the greatest amount of injury can be found by tracking injury rates for various locations in the body.

Figure 1-4 shows the locations (some injuries effecting more than one location) of the 140 injuries documented during the study.

Injury Location:	# of Injuries at Location:
Head	3
Neck/Upper Back	9
Shoulder	21
Elbow	2
Wrist	1
Hand	1
Trunk	2
Lower Back	50
Hip/Buttocks	6
Thigh	2
Knee	32
Leg	7
Ankle	10
Foot	3
Total	**149**

FIGURE 1-4: INJURY LOCATIONS (PRUSACZYK, 2000)

The locations with the most frequent injuries (highlighted rows) are joints that would regularly absorb energy from mechanical shocks, since they are used for either load bearing or balance/support. The fact that these areas are also the most frequently injured supports the correlation between the mechanical shock environment on the boats and the increase in acute and chronic injury rates among SWCCs.

In order to further support a connection between mechanical shock exposure on HSPBs and increased occurrence of acute and chronic injuries, a comparison was made between hospitalization rates for the navy as a whole and the SWCC and Special warfare community. Figure 1-5 shows a graphic representation of these hospitalization rates.

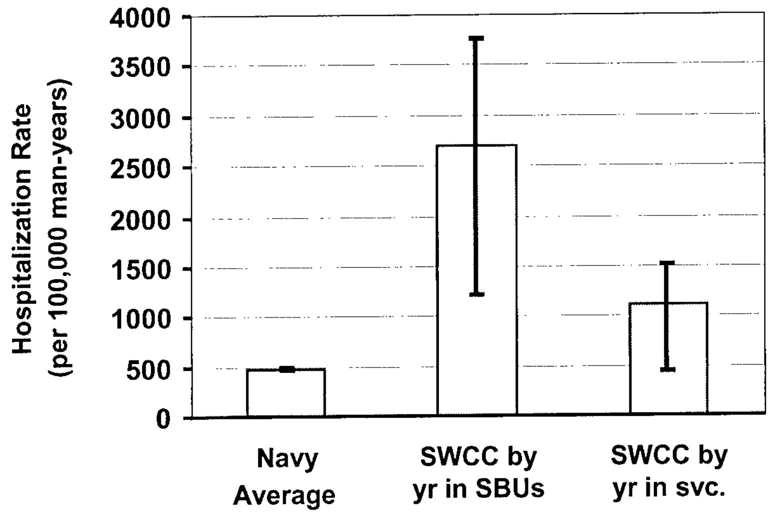


FIGURE 1-5: COMPARISON OF HOSPITALIZATION RATES (PRUSACZYK, 2000)

This comparison seems to clearly indicate a correlation between SWCC service on SBU boats and increased rate of injury requiring hospitalization. A more direct relationship between cumulative mechanical shock exposure and the occurrence of injury can be seen in Figure 1-6.

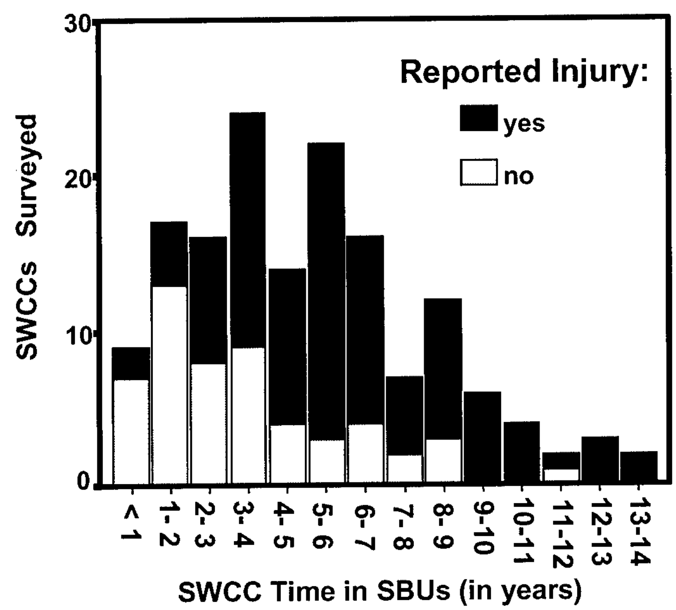


FIGURE 1-6: SWCC INJURIES WITH TIME IN SBUS (PRUSACZYK, 2000)

In this figure, the darker portion of each column represents the fraction of SWCCs surveyed who had been injured. As this figure shows, there is a trend toward almost 100% injury occurrence among SWCCs as their time with SBUs increases. This data appears to indicate a relationship between cumulative mechanical shock exposure and injury occurrence.

In response to the findings of the NHRC study and other similar studies and investigations, Special warfare began to actively campaign for research into this problem. The research done on this thesis project was in direct response to a request from Special Warfare Command in Coronado, CA to investigate the problem and provide findings and recommendations for design solutions.

Chapter 2

2.0 Examination of the Mechanical Shock Environment

2.1 Hull-Seaway Interactions (Theory)

Before proceeding, it is helpful to establish a standard coordinate reference system for describing and discussing mechanical shock events. The International Organization for Standardization has established guidelines for studying, measuring and reporting mechanical vibration and shock to humans (International Organization for Standardization, 1997). Figure 2-1 shows the ISO coordinate systems for sitting and standing humans.

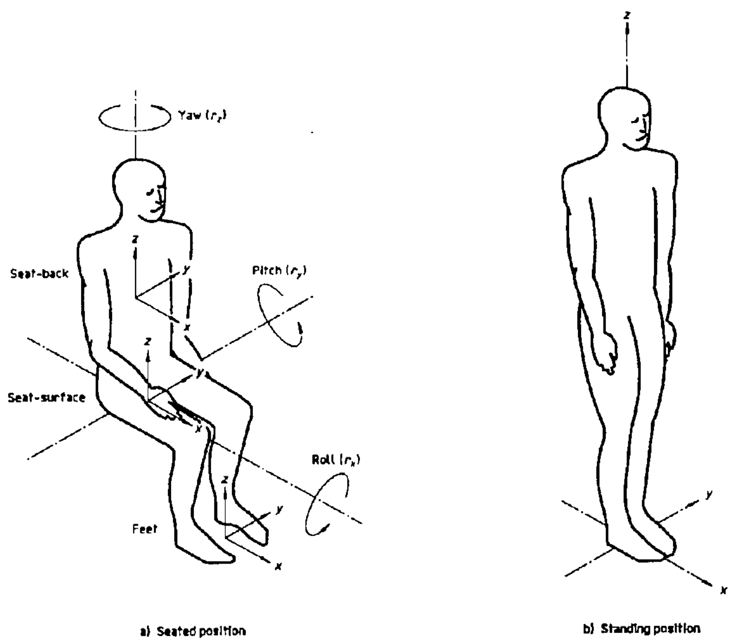


FIGURE 2-1: AXES OF THE HUMAN BODY
(International Organization for Standardization, 1997)

A look at the hydrodynamic interactions between a boat's hull and the seaway it operates in offer a good starting point in studying the source of the mechanical shock experienced on high-speed planing boats. For our purposes we will discuss mechanical shock in terms of pulses with a certain peak acceleration and waveform (relating to a natural frequency). While stopped or operating at low speeds in rough seas, planing boats behave much as any other mono-hull design, with relatively small accelerations at low frequencies, albeit with large motions especially in pitch and roll. While these oscillating rotational motions can cause great discomfort for the personnel on board, there is little risk of injury from them. It is when the boats begin to travel at higher speeds, especially once they are planing, that the hull-sea interactions become quite severe. The Special Boat Units typically operate in sea states of 3 or less, but depending on the mission needs, and other circumstances, high-speed operations in sea states of 5 or more are possible. In this type of sea environment, the two primary mechanisms through which mechanical shock occurs are wave slamming and vertical hull water entry. While these two interactions have similar hydrodynamic behavior, there are differences in the manner in which these two shock-producing events occur and the character of the shocks they produce.

2.1.1 Wave Slamming

Wave slamming involves the impact of the forward portion of the hull with oncoming waves as the boat heaves and pitches about a rotation point near the stern, with the aft portion of the boat remaining in contact with the sea. The hydrodynamics of wave slamming on boats and ships have been studied since the early 1900s. Many theories have been postulated for modeling and predicting the behavior of slamming. One of the earliest of these, expanding plate theory (von Karman, 1929), gives good approximations of the forces and motions involved without the need for extensive computations using digital computers. This theory was originally used to study the landing impact of seaplanes, but was later adapted for use in slamming forces on ships. Expanding plate theory is based on the assumption that the instantaneous flow around a two-dimensional wedge shape entering the water vertically, can be likened to the flow around a flat plate with the same width as the width of the wetted surface of the wedge at that instant, as shown in Figure 2-1.

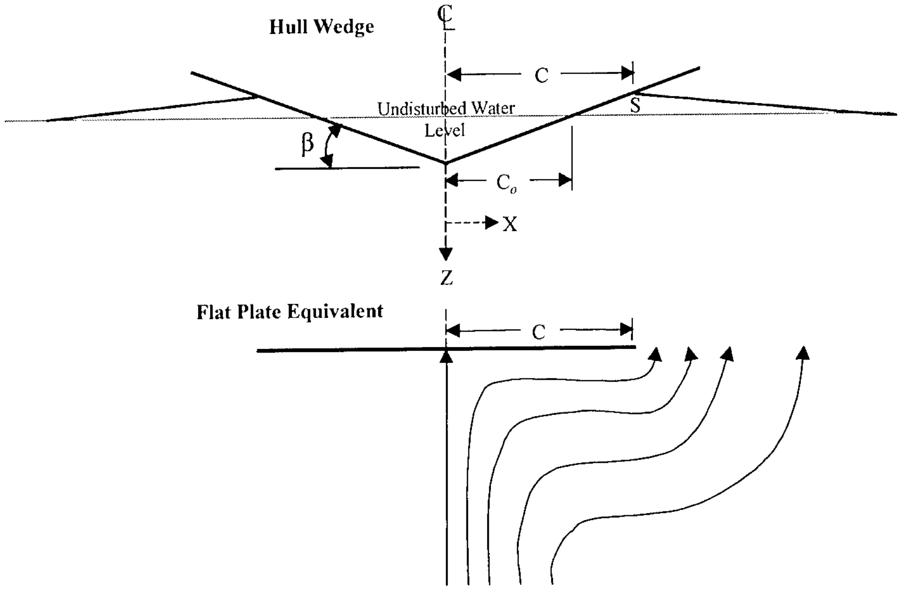


FIGURE 2-2: FLAT PLATE THEORY DIAGRAM

The angle a boat's hull makes with the horizontal plane is commonly called deadrise. We will further define the horizontal distance from the boat's centerline to edge of the waterline as the wetted semi-breadth. For an undisturbed surface, the wetted semi-breadth (C_o) of a hull wedge with dead-rise (β) is a function of its instantaneous draft (z):

$$C_o = \frac{z}{\tan \beta} \tag{2.1}$$

However, since the water surface is indeed disturbed by the entry of the hull section, the water level actually rises along the sides of the wedge as it enters. Wagner (1931) found the actual wetted semi-breadth (C_o) to be given by:

$$C = \frac{\pi C_0}{2} \tag{2.2}$$

Knowing the vertical velocity (v_0) of the hull wedge with respect to the wave surface, the rate of propagation ($\dot{C}$) of the wetted semi-breadth is:

$$\dot{C} = \frac{\frac{\pi}{2} v_0}{\tan \beta} \tag{2.3}$$

In Korvin-Kroukovsky's book on seakeeping, the local pressure (P_s) at the point of water-hull contact is approximated using the following equation:

$$P_s = \frac{\rho \dot{C}^2}{2} = \frac{\rho}{2} \left(\frac{\frac{\pi}{2} v_o}{\tan \beta} \right)^2 \tag{2.4}$$

This expression shows the pressure force at impact to be primarily a function of the vertical velocity and the dead-rise angle of the hull. This expression is based on a V-wedge hull with straight sides (which is similar to the hard-chine shape of the SBU boat hulls). However, this relationship can be applied to more complex hull forms. In 1931, Wagner showed that for a hull whose form could be represented by a polynomial such at the one shown below,

$$y = B_o x + B_1 x^2 + B_2 x^3 + \ldots + B_n x^{n+1} \tag{2.5}$$

the following relationship would hold:

$$\frac{v_o}{\dot{C}} = \tfrac{2}{\pi} B_o + B_1 C + \tfrac{4}{\pi} B_2 C^2 + \tfrac{3}{2} B_3 C^3 + \ldots \tag{2.6}$$

In 1954 M. A. Todd developed a set of equations of motion (based on Wagner's work) for specific ship model. A series of experiments were conducted in which the model was subjected to vertical water entry and the resulting accelerations were measured and compared to those calculated from the equations of motion. Good agreement was observed between the experimental and calculated accelerations as seen in Figure 2-2 (Korvin-Kroukovsky 1961).

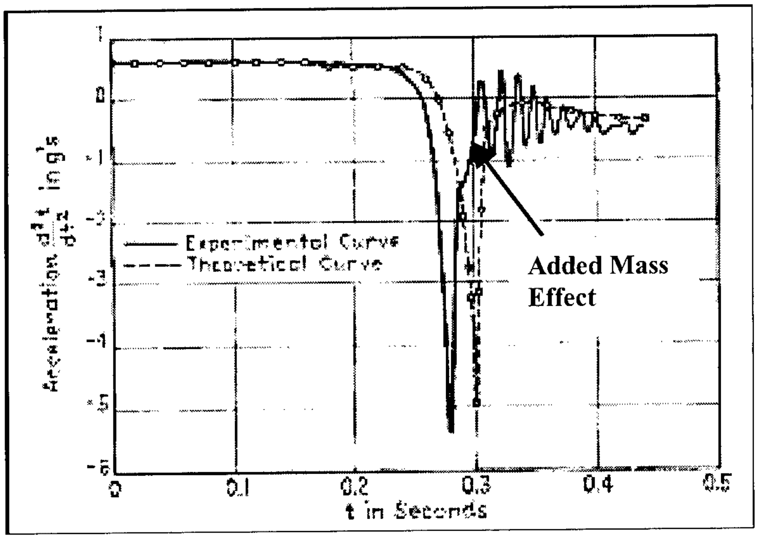


FIGURE 2-3: FLAT PLATE THEORY VS. EXPERIMENTATION (KORVIN-KROUKOVSKY, 1961)

The bulge that appears on the upsweep of the empirically obtained pulse is due to added mass effects, which are not accounted for in the theoretical calculations. It is interesting to note that these shock pulses have peak accelerations of about 5 g's with pulse widths of roughly 50 milliseconds. It will be seen later in this section that these values are quite similar to shock events measured on SBU boats.

2.1.1 Vertical Hull Water Entry

Hull water entry occurs when the entire boat leaves the surface of the sea (e.g. flies off the crest of a wave) and then re-enters the water from some height and at some angle relative to the sea. Although the same general theory discussed with wave slamming applies here, the mechanics are now potentially more complex since when the boat leaves the surface of the water the hull can return in a variety of aspects with respect to the surface of the sea. Depending on the angle at which the hull re-enters the water, the severity and nature of the shock pulse that results can vary significantly.

While any specific case of hull water entry can be treated in a manner similar to the wave slamming case, it relies on knowledge of the relative geometry between the hull and sea at the time of impact. This geometry is a function of many known or predictable factors (e.g.- sea state, boat size, shape and mass, speed) as well as more random factors such as boat speed and the manner in which the boat is operated (human factors) and the boats motion while airborne. Because of this uncertainty, it is impossible to adequately predict the expected shock pulses for a generic boat-sea-speed situation. What is possible, however, is to analyze the boat response under a range of different angles of water entry. This allows analysis of the non-symmetric forces, which result from off axis water entry. Such off axis impacts can result in significant longitudinal and lateral mechanical shock forces, and the NSW RHIB is especially prone to such effects due to its smaller size and lighter weight. Zhao, Faltinsen and Aarsnes conducted an analytical treatment of this hull water entry problem, along with empirical validation of their predictions (1996). Dr. Ronald Peterson from the Navy Coastal Systems Station in Panama City, FL has worked on the development of a computer program to model hull water entry. This program, called WEDIM (Water Entry Dynamics and Injury Model), has also been validated against empirical results and is a useful tool in predicting the mechanical shock forces experienced on high-speed planing boats (Peterson, 2000).

2.2 Empirical Shock Measurements

2.2.1 Magnitude and Timeline Data

Theoretical knowledge of how mechanical shock forces result from interactions between a boat's hull and the sea are useful to the overall understanding and modeling of the problem, but actual shock data recording is still needed in order to determine the specific behavior of the boats under various sea conditions. Initial investigation into the shock environment on board the SBU boats was performed using a SnapShock-PLUS self-contained acceleration recorder from Instrumented Sensor Technologies (IST). This recorder (Figure 2-3) measures and stores the date, time, peak acceleration, and pulse width of up to 5900 shock events.

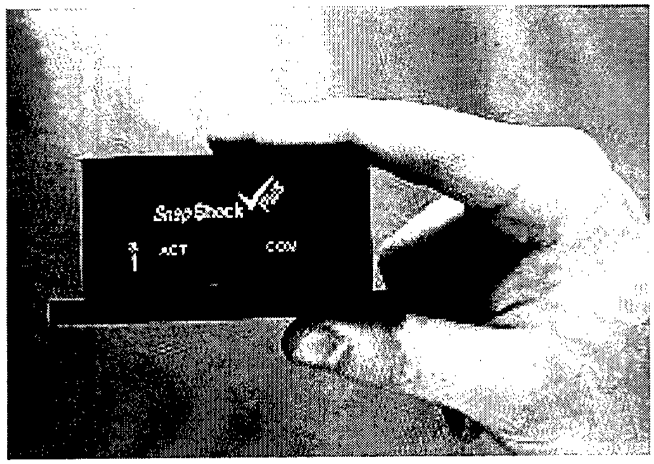


FIGURE 2-4: IST'S SNAPSHOCK PLUS ACCELERATION DATA RECORDER (photo from www.ist.com March, 2001)

Because of its small size and tough construction, this recorder was well suited to use out on the SBU boats where it was subjected to sea spray, heat, cold, vibration and of course mechanical shock. The recorder was used during a trip to SBU-20 in Coronado, CA in August of 2000. While out at SBU-20, shock data recordings were made on both the NSW RHIB and the MkV SOC during typical operations at sea. On the days data was taken, conditions were sea state 2 to 3, with light winds. Following the data collection runs, the SnapShock PLUS data was downloaded to a laptop PC for review and processing. A summary of the shock data from the two boat runs is shown in Figures 2-4 and 2-5 below.

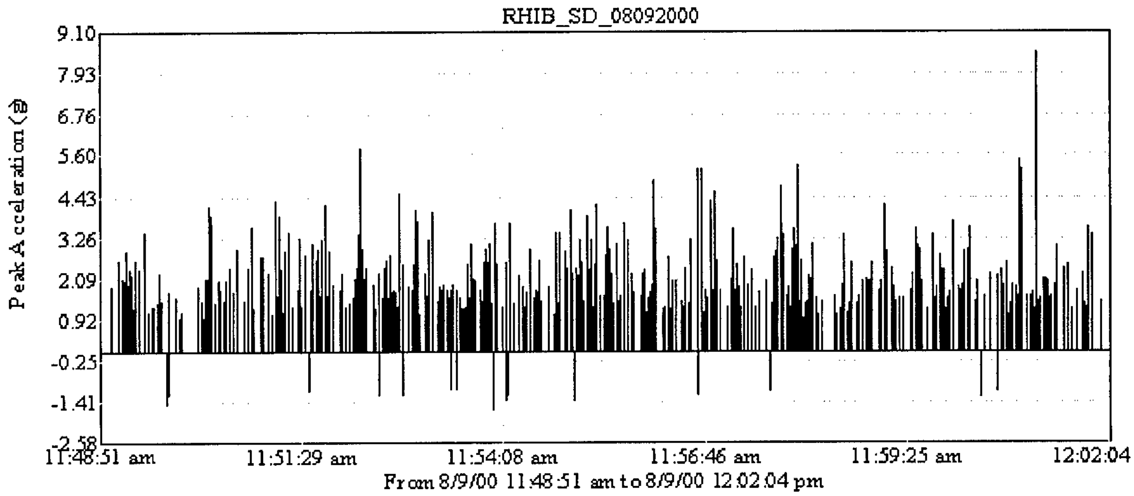


FIGURE 2-5: NSW RHIB SHOCK DATA TIMELINE SUMMARY (AUGUST 2000)

The data shown in these timelines are for vertical accelerations. Only the magnitude of the shock and the time at which it occurred can be read from the figures. Although the SSP recorder does not provide full waveform data, it does give both the magnitude and pulse width of the shocks, in tabular format. This data is located in the Appendix A.

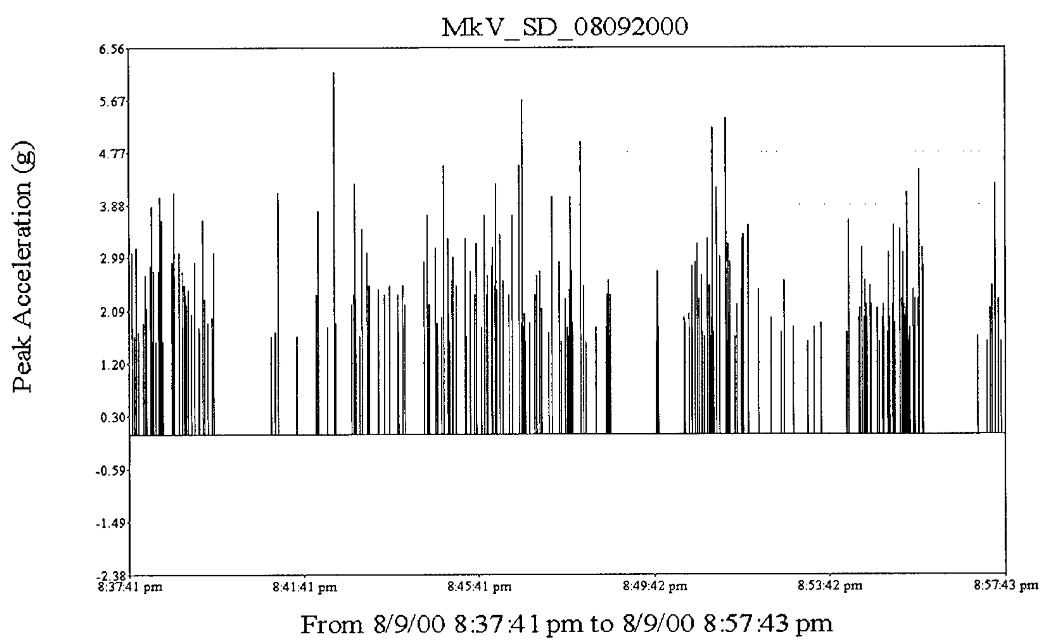


FIGURE 2-6: MKV SOC SHOCK DATA TIMELINE SUMMARY (AUGUST 2000)

This data was useful in obtaining a preliminary understanding of the types of magnitude and duration shocks experienced on the SBU boats. The timelines shown here demonstrate the existence of a significant mechanical shock environment, which certainly has the potential to cause discomfort and injury. However, since the data recorder did not provide actual waveform information, the ability to post process the data was limited. In order to use the data from these tests, the shocks were assumed to be half sine wave pulses with amplitude equal to the peak acceleration and the half sine wave period equal to the pulse width of the recorded shock. This data was then processed to generate shock spectra for a generic mass-spring damper system, such as the one shown in Figure 2-6.

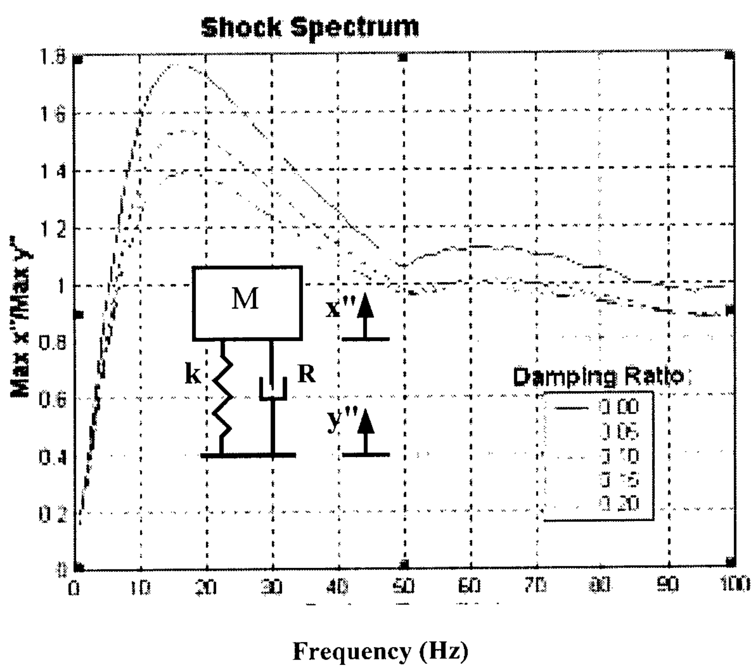


FIGURE 2-7: SAMPLE SHOCK SPECTRUM FOR A 50 MSEC SHOCK PULSE

The shock spectrum shown above gives the ratio of system response to base excitation in terms of acceleration. The system parameters are spring stiffness (k), damping coefficient (R) and mass (M). The base excitation for the spectrum shown is a half sine wave shock pulse 50 milliseconds in duration. It can be seen that the system response for this case has a maximum near 16 Hz. While the information available from these spectra is useful, it is necessary to obtain accurate time history shock data from the boats in order to get the best representation of the shock environment.

While the focus of this study deals primarily with shock events occurring in the vertical or z-direction, the significance of both lateral (y-direction) and longitudinal (x-direction) shocks cannot be ignored. For boats such as the MkV, which are relatively large and massive compared to most special warfare boats, the magnitude of lateral and longitudinal shocks is relatively minor in most sea states. However, boats like the NSW RIB can experience severe lateral and longitudinal shocks due to their much smaller weight and size. Figure 2-7 shows a timeline of NSW RIB lateral shock data taken in relatively mild seas of 1-2 feet significant wave height.

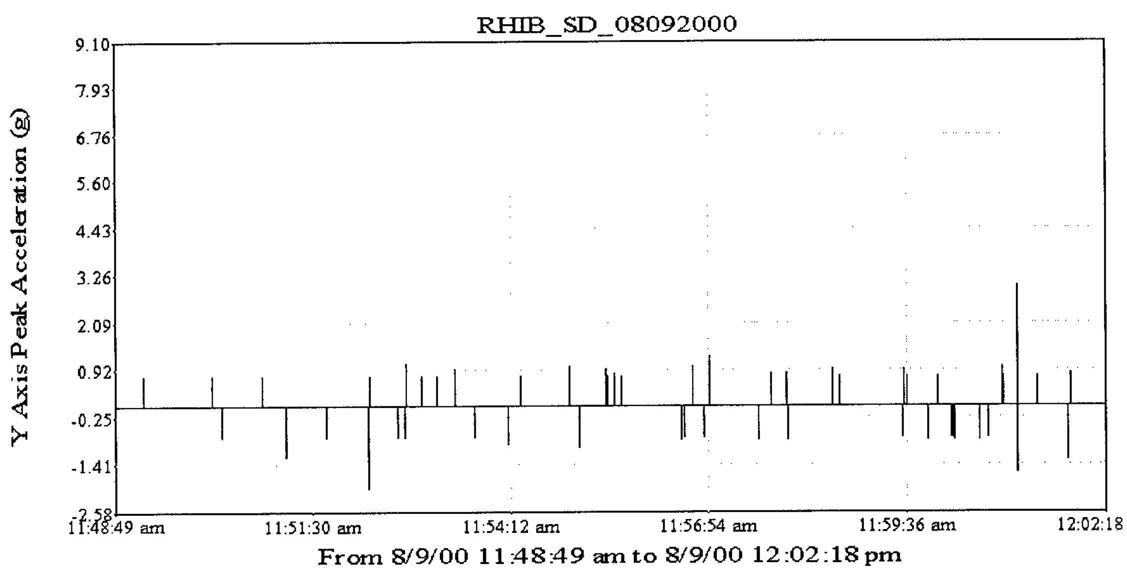


FIGURE 2-8: LATERAL SHOCK TIMELINE FOR NSW RIB

While the shock magnitudes shown here are not nearly as large as those in the vertical direction, they are still significant since the body (especially the head-neck complex) is not well adapted to withstanding these types of shocks. Another important point is that this shock data was taken at the deck surface on the RIB. The occupants standing up in this boat experience a more severe shock due to the added effect of the boat's roll rate as it rights itself during wave impacts. This motion produces a snapping or whiplash effect on the head-neck complex, which can potentially result in discomfort and injury. These lateral shocks also put significant load on occupant's shoulders, arms and wrists as they hold onto railings and handlebars to keep from being thrown from the craft. Similar shocks can be seen in the longitudinal direction when the boat enters a wave in a "nose-in" or "nose-down" angle (often referred to as "stuffing"). Although instances of stuffing the boat are much less common, they represent yet another potential injury causing shock load on the occupants.

2.2.2 Waveform Data

In order to record time history (i.e. - waveform) type shock data, a different recorder was needed. IST produces a larger and more capable version of the SnapShock Plus recorder used initially. This EDR-3 recorder (Figure 2-8) measures up to 6 input channels of acceleration data

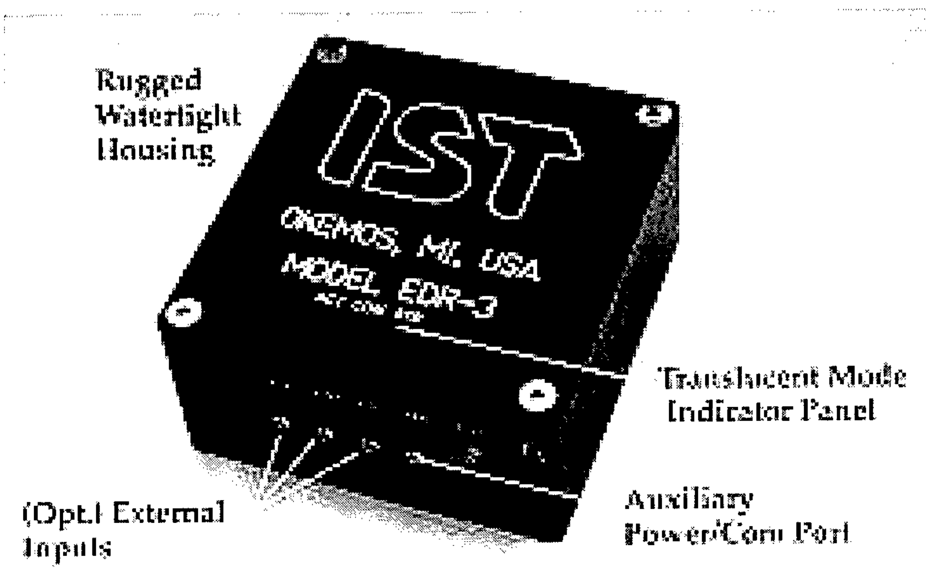


FIGURE 2-9: IST'S EDR-3 ACCELERATION RECORDER
(photo from www.ist.com March, 2001)

and records them in time domain format at a sampling rate set by the user. Due to cost restrictions, it was not possible to obtain one of these recorders. However, shock data taken with these recorders was obtained from Combatant Craft Department (CCD) of the

Carderock Division of the Naval Sea Systems Command (NAVSEA) in Suffolk, VA. During the mid to late 1990s, CCD conducted several craft motion studies on the MkV SOC and other Special warfare high-speed boats (Haupt 1996, 1997). During these studies, EDR-3 recorders were used to log 3-axis acceleration data at several locations on the craft in a variety of sea state and boat speed combinations. Data from these tests was obtained for use in this study. The raw data collected by shock recorders often contains higher frequency components (depending on the sampling speed, recorder location and the manner in which the recorder is secured). In general these higher frequency components are not of interest since the human body does not respond to them significantly. The data was filtered to remove higher frequency components above the range of frequencies at which the human body will respond (this is discussed in detail in chapter 3). Figure 2-9 shows a typical shock event waveform.

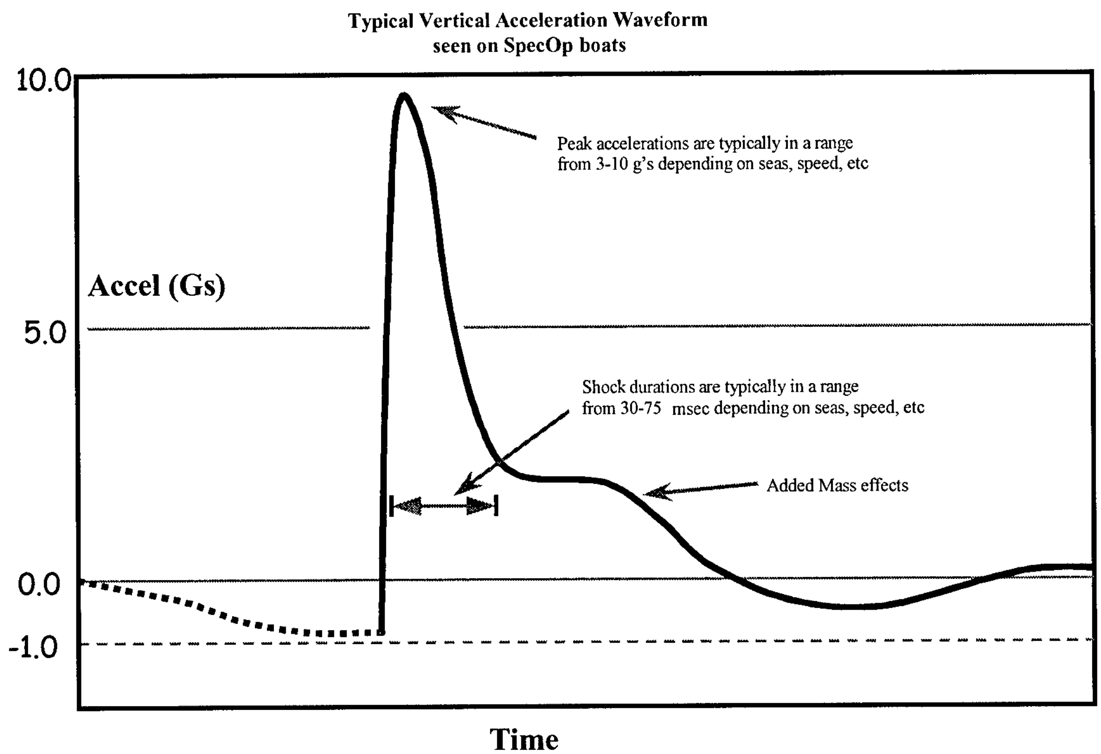


FIGURE 2-10: TYPICAL VERTICAL ACCELERATION WAVEFORM

The shock event shown is a generic one, but is representative of the typical vertical shock loads experienced on the boats. The general shape of the waveform is fairly consistent, with a sharp leading edge, less steep trailing edge and a bulge near the lower trailing edge due to added mass effects of the hull-water interaction. The peak acceleration and average pulse width of these shock events varies depending on sea state, boat speed, winds, driver boat handling skills, and location on the boat. Typically, the pulse widths are 50 milliseconds or less in duration, with magnitudes varying according to the vertical velocity at the moment of impact. This velocity at impact depends largely on the height from which the boat drops, relative to the water surface and the dynamic theory which predicts this behavior was validated by Peterson, Wyman and Frank (1997). Figure 2-10 shows a summary of shock data taken at the coxswain station on the MkV SOC during CCD's MkV SOC Craft Motions Test.

MkV SOC Craft Motion (Coxswain station in 2.5-3 ft seas @ 35 knots)						
	Peak Accelerations			Shock Pulse Duration		
	Longitudinal (g's)	Lateral (g's)	Vertical (g's)	Longitudinal (sec)	Lateral (sec)	Vertical (sec)
Max	10.4	2.84	7.13	0.037	0.201	0.346
Min	0.22	0.17	0.36	0.004	0.002	0.002
Avg	1.43	0.86	2.99	0.012	0.018	0.033
1/3	2.31	1.32	4.82	0.016	0.034	0.087
1/10	3.40	1.87	5.83	0.021	0.055	0.180

FIGURE 2-11: MKV SOC CRAFT MOTION TEST DATA SUMMARY (HAUPT, 1997)

During the MkV SOC Craft Motion Test, the EDR-3 recorders were set to record any vertical shock event over 0.5 g's in peak acceleration. Due to this relatively low threshold setting, a large number of minor shock events were recorded, and the average values are therefore lower than they would have been had only the significant shock events been recorded. The 1/3 and 1/10 highest average values are perhaps more representative of the shock events seen on the boats. Of note here is the fact that the seas during these tests were in the range of 2.5 to 3 ft significant wave height, which equates to sea state 3. The special warfare boats often operate in much rougher seas (up to sea state 5 or more) with the accompanying increase in mechanical shock severity.

At this point we have established a correlation between time spent on special warfare boats and an increase in both acute and chronic injury rates. We have also determined, through both theoretical predictions and empirical measurements, that severe mechanical shock environments exist on these boats when they operate at high speeds in rough seas. The direct connection between the injuries and the shock environment is the missing piece and will be discussed in the next section.

Chapter 3

3.0 Mechanical Shock and Injury - Making the Connection

3.1 Human Body Response Testing

In order to determine the relationship between mechanical shock exposure and injury or discomfort in humans, it is necessary to understand the way in which the human body responds to vibration and shock. While there is certainly an abundance of circumstantial and anecdotal evidence to connect mechanical shock exposure with injury, more definitive and quantitative relationships are needed in order to effectively study and solve the problem.

In analyzing mechanical shock and its effects, there are many schools of thought on what physical parameter should serve as the basis for determining shock effects. Displacement, velocity and acceleration are the most likely choices, and arguments have been made for the use of each. However, the typical standard is the use of acceleration data as the basis for shock and vibration study. This is due in part to the relative ease with which acceleration data can be obtained as compared to velocity and displacement data. While compelling arguments have been made that velocity and pseudo-velocity may be good indicators of shock severity (Gaberson, 1969 and 1995), for the purposes of this report the acceleration data standard will be used. This data will be used and discussed in its raw or filtered form only. There various schools of thought on whether to analyze the data in raw form, root mean squared (rms) form, or even root mean quadrupled (rmq) form. In actuality, the form in which the acceleration data is analyzed has little or no effect on the qualitative results obtained. In addition, the rms or rmq forms of acceleration data are more for use with oscillatory vibrations rather than the random individual shock events seen on high-speed boats (Griffin, 1990).

The analysis of human body response is difficult due to the complex nature of the human body itself. The body is both a mechanical and biological system and its behavior is governed by the combined mechanical and biological properties. Not only do the properties of the human body vary significantly from those of inanimate physical systems, but they also vary largely from one human to another and even within a given human. Factors such as heredity, diet, daily physical activity, history of injury or sickness, and overall physical fitness, can cause dramatic differences in how one person's body reacts to mechanical shock as compared to another person. (Griffin, 1990)

The study of human response is also complicated by more practical concerns, such as the risk of injury to the humans being studied. At the present, there is not much reliable data on the types of force (both magnitude and duration), which will result in pain or injury to humans. In order to avoid subjecting human beings to unnecessary or unacceptable risk, it is common to use animals as surrogates for testing. On top of the fact that animal testing has come under increased criticism and public outcry in recent years, the use of animals as experimental subjects for injury mechanism tests brings with the added complication of determining the correlation and applicability of the test data to actual human response. Animals differ from humans in size, anatomy, and physiological structure. These differences can result in marked disparity between the biodynamic response of the animal and humans. Despite the difficulty in using animals as test subjects, much useful data has been obtained in this manner (von Gierke, 1996).

Another challenge in testing human body response is in reproducing the mechanical shock environment to which personnel are exposed. In order to obtain valid data, the magnitude and time history of the mechanical shocks used in testing typically must match quite closely the real life shocks. Due to the wide variety of shock environments to which humans are exposed, a large number of testing devices have been developed to properly reproduce these shocks. Figure 3-1 lists the most common shock and vibration testing machines and their characteristics.

TYPE OF MACHINE	APPLICATION OF FORCE	FORCE-TIME FUNCTION	FREQUENCY RANGE	MAXIMUM AMPLITUDE
SHAKE TABLE			MECHANICAL 0-50 Hz	UP TO 15g
			ELECTRODYNAMIC 15-1,000 Hz	
VERTICAL ACCELERATOR			0-10 Hz	±10 FT, 3.7g PEAK
SHOCK MACHINE			DOWN TO T = 0.16 SEC τ = 2.10⁻³ SEC	PEAK AMPLITUDE 10⁻² TO 10⁻¹ CM
HORIZONTAL OR VERTICAL DECELERATOR OR ACCELERATOR (SLEDS ON TRACKS, CAR, DROP-TOWER)			RATE OF ACCELERATION UP TO 1,400 g/SEC	40g PEAK
BLAST TUBE FIELD EXPLOSION				
SIREN (AIRBORNE SOUND)			25-100,000 Hz	160-170 dB RE 20 μPa
RESPIRATOR			0-15 Hz	
VIBRATOR (SMALL PISTON)			0-10 MHz	
SHAKER ON CENTRIFUGE	ALTERNATING g FORCE IN ADDITION TO STATIC g FIELD		0-3 Hz	
HEAD IMPACT MACHINE FOR DUMMY HEADS			DEPENDING ON STRUCTURE STRUCK	IMPACT VELOCITY 140 FT/SEC

FIGURE 3-1: SHOCK AND VIBRATION TESTING MACHINES (VON GIERKE, 1996)

While this section focuses mainly on the results of previous human and animal testing, chapter 5 will discuss in more detail the use of various test machines in designing, testing and evaluating shock mitigation systems. (von Gierke, 1996)

Although extreme dynamic testing of humans is not feasible, it is possible to measure some human mechanical properties when the forces required to obtain these measurements are small. Another avenue for testing is the use of cadavers, which can be employed in obtaining data on the properties of human bones, cartilage and connective tissues under failure loads. These two methods provide data on the actual physical properties of the human body and its dynamic behavior, which can then be used to develop numerical models of humans for computer based simulation. The work in this area (which will be discussed in more depth later) is still in its infancy but may ultimately be the safest and most effective way to model and predict human body response, injury mechanisms, and tolerance limits. (von Gierke, 1996)

A final method of data collection involves the study of actual human injuries that occurred due to exposure to mechanical shock. In most such cases, it is possible to obtain detailed information on the type and extent of the resultant injuries. However, it is often difficult to determine the magnitude and nature of the mechanical shock, which caused them, or the manner in which the injury actually occurred (i.e.- the injury mechanism). Still, certain instances (such as a pilot using his ejection seat) have a more discernible cause and effect relationship, which can provide useful information. The Dynamic Response Index (which is discussed in detail later) is an example of an injury prediction model based on this type of data (Griffin, 1990).

3.2 Transmissibility and Mechanical Impedance of the Body

To better understand the human body's behavior in response to shock and vibration, it is important to know how these forces are transmitted and dissipated in the body. Transmissibility is typically described as a ratio (e.g.- of displacement, velocity, or acceleration) between the point where the excitation energy enters the body and some other point (typically the head). The majority of research on human body transmissibility and impedance focus on the body's response to vibration or shock in the vertical direction. In Chapter 2 it was discussed that the most significant mechanical shock exposure on special warfare boats is in the vertical direction, so the available research data is largely applicable to our case. Still, it is important to note the significant lateral and (sometimes) longitudinal shocks experienced by occupants of certain smaller craft, and the injury risks these shocks pose. While no detailed analysis of human body response to lateral or longitudinal shock will be discussed here, the severity of injuries (especially to the head-neck complex), which may potentially result from these sorts of shocks, is compelling (Backaitis, 1993). Figure 3-2 shows seat-to-head transmissibility curves for a single seated human exposed to vertical vibrations at various frequencies on 12 separate occasions.

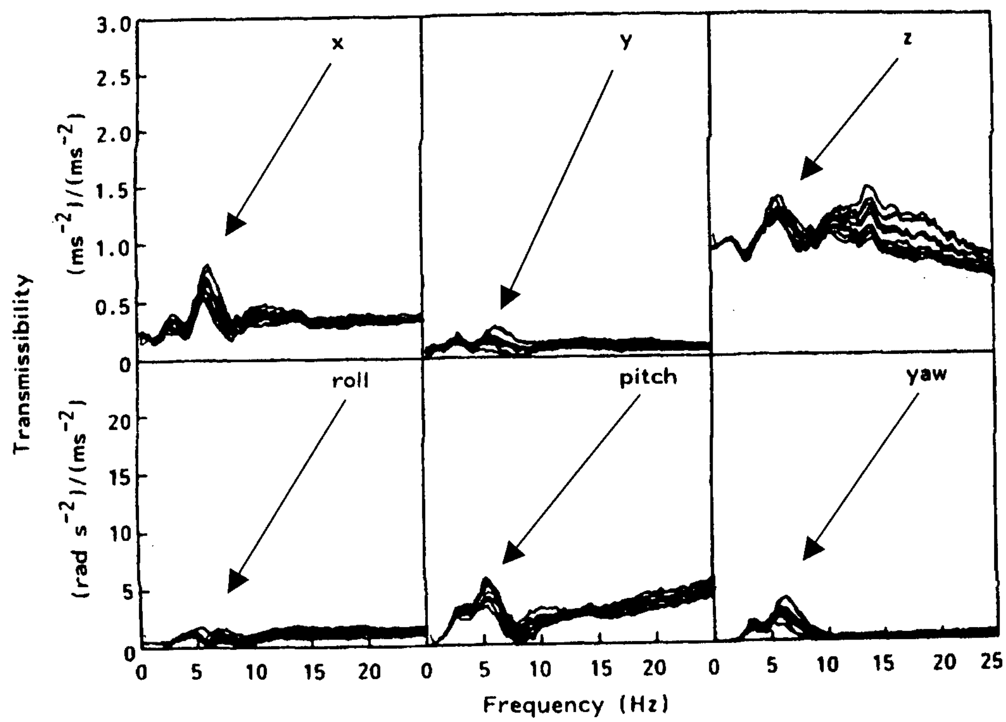


FIGURE 3-2: SINGLE TEST SUBJECT SEAT TO HEAD TRANSMISSIBILITY CURVES (GRIFFIN, 1990)

Note the variation in transmissibility between the different curves, all measured from the same human test subject. This is a good example of the intra-human variability in response behavior, which can exist for a single individual. Despite the variation, the behavior is mostly consistent and shows peak transmissibilities in the range of 4-6 Hz. As we will see later, this frequency range corresponds to one of the human body's primary resonant frequencies. Figure 3-3 shows similar transmissibility curves, this time taken for a group of 12 separate test subjects.

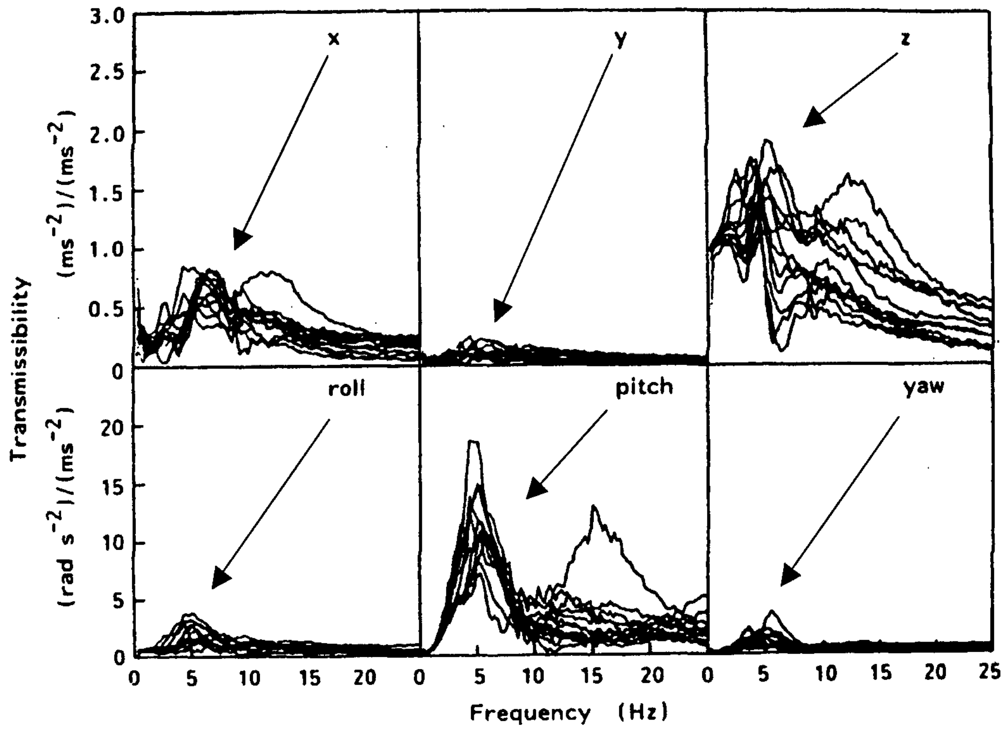


FIGURE 3-3: MULTIPLE TEST SUBJECT SEAT TO HEAD TRANSMISSIBILITY CURVES (GRIFFIN, 1990)

The inter-human variability of dynamic response is quite obvious in this figure, but the peak transmissibilities are still seen at or near the range of 4-6 Hz. While by no means the final word on human body response, this transmissibility data certainly points to a frequency range, which is potentially more damaging and worth avoiding if possible.

Compilations of transmissibility studies and data lead to the creation of lumped parameter models of the human body, which allow quantitative analysis of human response to given input excitations. Figures 3-4 and 3-5 are two examples of such models.

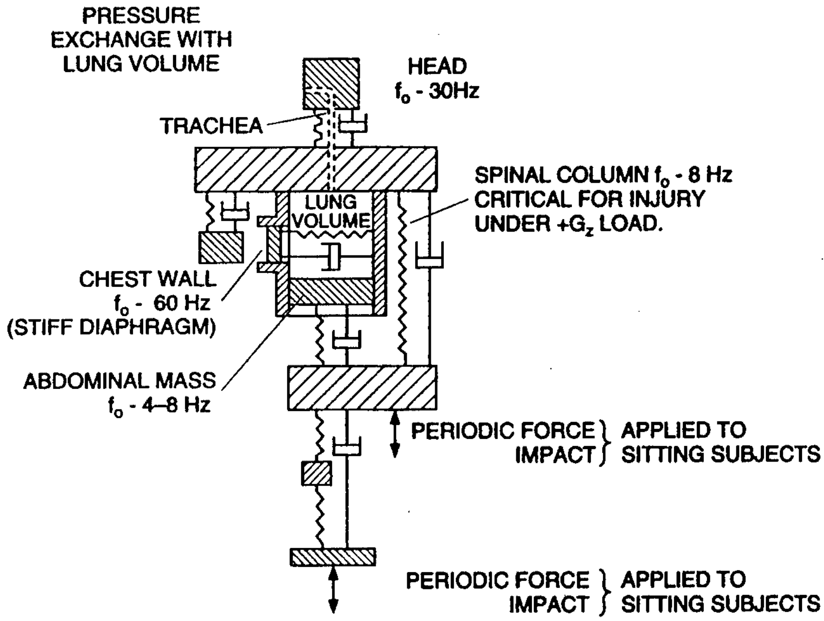
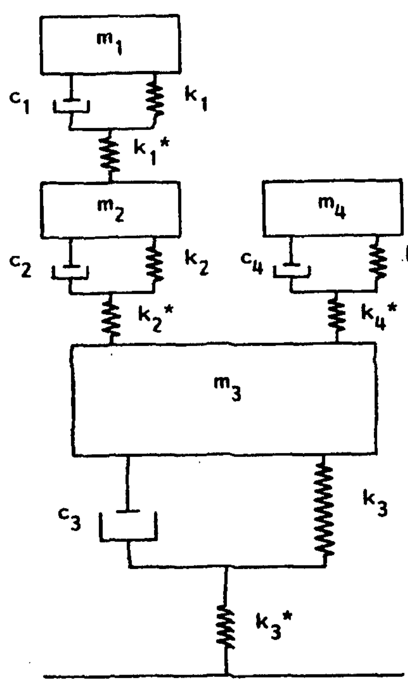


FIGURE 3-4: SIMPLE BIODYNAMIC MODEL OF SITTING OR STANDING HUMAN (VON GIERKE, 1996)



Model parameters	
m_1	8,24 kg
m_2	8,05 kg
m_3	44,85 kg
m_4	13,86 kg
k_1	22×10^8 N.m^{-1}
k_2	$20,13 \times 10^4$ N.m^{-1}
k_3	$88,56 \times 10^3$ N.m^{-1}
k_4	$36,47 \times 10^3$ N.m^{-1}
k_1*	36×10^7 N.m^{-1}
k_2*	65×10^9 N.m^{-1}
k_3*	$52,34 \times 10^4$ N.m^{-1}
k_4*	$69,30 \times 10^3$ N.m^{-1}
c_1	748,1 N.s.m^{-1}
c_2	578,0 N.s.m^{-1}
c_3	2964,0 N.s.m^{-1}
c_4	901,8 N.s.m^{-1}

FIGURE 3-5: FOUR DEGREE OF FREEDOM BIODYNAMIC MODEL (ISO, 1981)

As discussed earlier, these models are for vertical transmissibility only, and do not allow prediction of head-neck motion in (in pitch, roll, etc.) which can result from excitation in the z-direction. Nonetheless, simple models such as these, along with many other similar models of varying detail and complexity, allow computer-based simulation of human body response to mechanical shock environments. This type of testing allows large numbers of "experiments" to be run without harming humans or animals, and the incorporation of design tools allows iterative approaches to design solutions. This is a largely unexploited avenue of research in the area of mechanical shock exposure on high-speed small boats.

One of the simplifications used in many of the current human biodynamic models is the use of lumped pure masses instead of the actual distributed mass of the body. The mechanical impedance of the human body is defined as the complex ratio between the dynamic force applied to the body and the velocity at the interface where the force is applied (von Gierke, 1996). The body is made up of many tissues with varying stiffness, density and other properties, so it does not behave as an ideal pure mass. Figure 3-6 shows the mechanical impedance behavior of standing and seated humans as compared to an ideal pure mass.

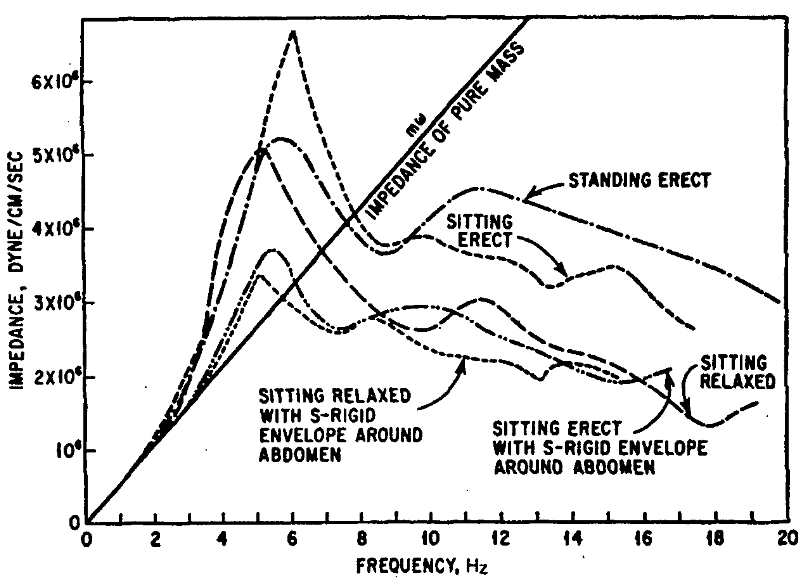


FIGURE 3-6: MECHANICAL IMPEDANCE OF STANDING AND SEATED HUMAN (VON GIERKE, 1996)

As the chart shows, the human body impedance matches that of a pure mass at frequencies below 2 Hz, and follows the behavior of pure mass over the range of low frequency up to about 6 Hz. At higher frequencies, the human body behaves much differently than pure mass and this difference can introduce significant error in the predictions of human biodynamic models, which do not properly account for it. The use of lumped mass in human models will be addressed further in Chapter 5.

3.3 Relating Human Response to Injury Risk and Tolerance Limits:

While knowledge of human body transmissibility and mechanical impedance allows modeling and prediction of the response and stresses resulting from mechanical shock exposure, it does not provide any direct information on injury risk. As stated previously, the ability to correlate injury potential with shock exposure is complicated by the limitations on testing of humans and the limited applicability of animal testing data. Despite this, several studies have been conducted which provide quantitative information on the relationship between shock and injury or discomfort. P.R. Payne developed one such method, the Dynamic Response Index (DRI), in the 1970s. Applicable for humans in a seated position, the DRI is based on the assumption that the human torso can be modeled as a simple mass-spring-damper system, and that the response of this system to mechanical shock can be directly related to discomfort or risk of injury. The DRI model is based on years of collected air force ejection seat data and as Figure 3-7 shows, the model predictions agree quite well with actual operational experience.

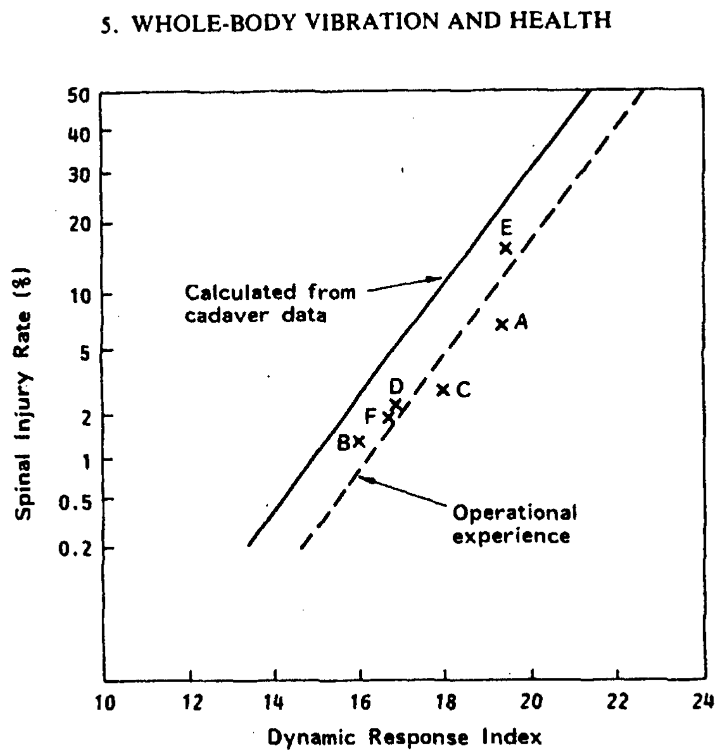


FIGURE 3-7: COMPARISON OF DRI PREDICTIONS TO ACTUAL INJURY RATES (GRIFFIN, 1990)

In the figure, the solid and dashed lines represent spinal injury rates derived from cadaver tests and operational injury data compilations respectively. The lettered X's in the figure represent the predictions of the DRI model. The DRI model is based on a natural frequency of 8.4 Hz with a damping ratio of 0.2245, which is intended to represent the typical characteristics of the human torso complex. By applying a known shock pulse to the model, the maximum deflection (δ) can be determined. This deflection is converted into a peak acceleration (which is proportional to the peak spinal stress) by multiplying it by the square of the natural frequency (ω_η). This number is in turn converted into the non-dimensional DRI number by dividing through by the acceleration of gravity (g).

$$DRI = \frac{\delta \bullet \omega_\eta^2}{g} \qquad \textbf{(3.1)}$$

The DRI model, although far from perfect and viewed with skepticism by some, is one of the only injury prediction models available for mechanical shock exposure and commonly used by designers in shock isolation. (Griffin, 1990)

3.4 Effects of Prolonged Exposure to Mechanical Shock

As stated earlier, the use of cadavers in testing can yield valuable information on behavior of the human body, especially the muscular-skeletal system under stresses, which cause permanent damage. The results of one such study are shown in Figure 3-8.

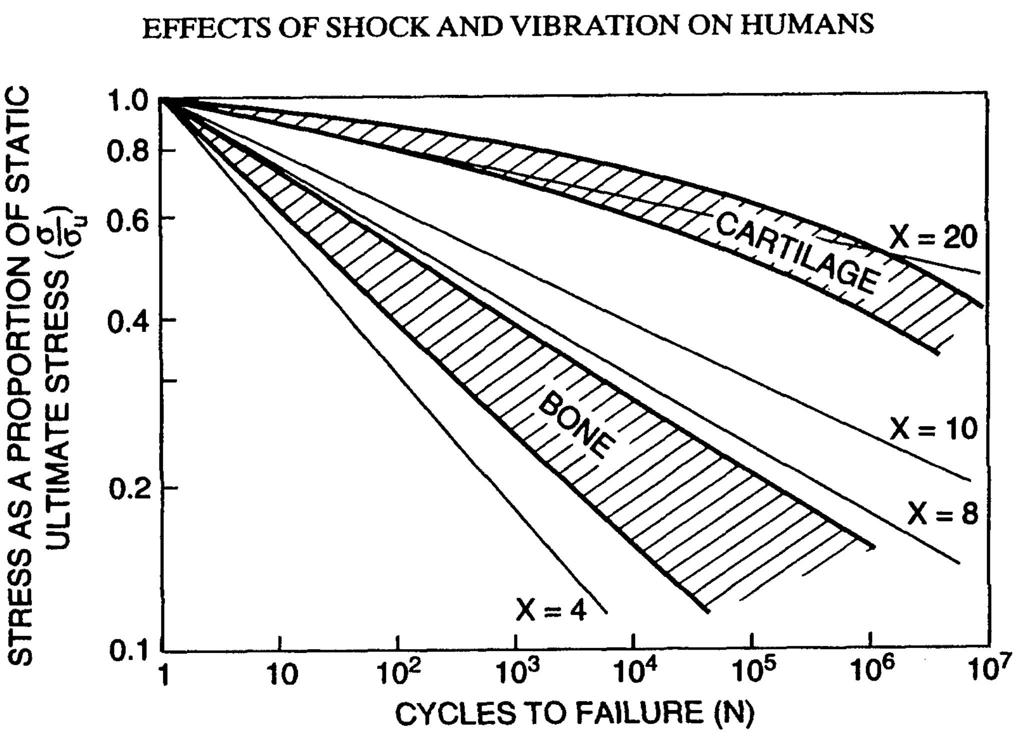


FIGURE 3-8: EFFECT OF FATIGUE ON BONE AND CARTILAGE FAILURE (VON GIERKE, 1996)

The information in this figure shows a definite trend of weakening in bones and cartilage under repeated cycles of stress like those experienced from mechanical shock. In this figure, the straight lines represent the function

$$N = \left(\frac{\sigma}{\sigma_u} \right)^{-x} \tag{3.2}$$

with the index value (x) shown for the various lines (von Gierke, 1996). While the reduction in bone strength is more immediate and severe, the weakening of cartilage is also significant since the yield stress of cartilage is much lower than that of bone and smaller shocks will still cause cartilage fatigue. This data, and other similar studies, validate the trend discussed in Chapter 1 in which the incidence of injury for personnel assigned to special warfare boat units increases as their total time spent aboard the boats grows. The mechanics of lower back injuries, which represent a large portion of the injuries experienced on the special warfare boats, are especially affected by past exposure to mechanical shock stresses and injuries (Ghista, 1982).

While the DRI chart shown in Figure 3-6 shows the predicted and actual injury rates for single instance shock events (i.e.- ejection seats), the correlation between prolonged exposure to repeated mechanical shock has been identified as a factor in lowering the injury risk limits. This shock exposure relationship is accounted for in the DRI chart shown in Figure 3-9.

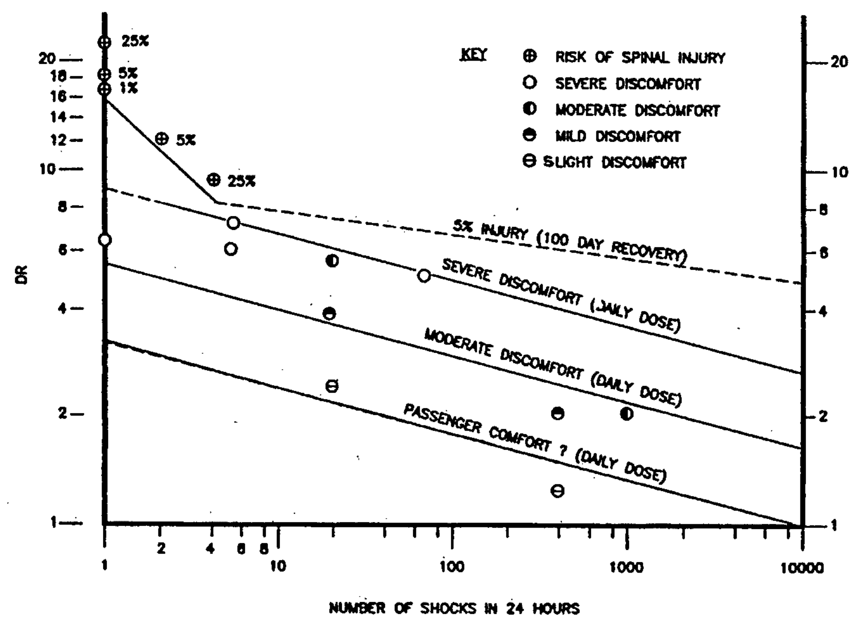


FIGURE 3-9: TENTATIVE INJURY AND DISCOMFORT LIMITS FOR REPEATED SHOCKS (VON GIERKE, 1996)

This chart offers a much more useful method of injury prediction for personnel subjected to prolonged exposure to mechanical shock. However, the primary limitation of this injury prediction model is that it applies only to personnel who are seated. The personnel aboard special warfare boats are most often in some sort of standing, or standing and leaning, posture, utilizing "standing bolster" style supports. At the moment there is no injury prediction model available to apply to these types of posture.

3.5 Effects of Posture on Human Response

The previous section ended by mentioning that there are no injury prediction models available for many of the postures in which the special warfare boat operators find themselves. While no definitive injury risk data is available on these postures, there is significant understanding of how posture affects the manner in which the human body responds to vertical axis mechanical shocks. For instance, one of the drawbacks of the conventional seated position is that it prevents the spine, especially the lumbar region, from adopting the optimal configuration to absorb and respond to shock. In order for the spine to be in an optimal or near optimal configuration while sitting, the thighs must be rotated down about 30 degrees below horizontal. This posture properly positions the pelvis to align the spine for optimal lumbar curvature. A conventional seat does not allow this position, and bends the lumbar region of the spine into poor geometry for absorbing shock. The next chapter will discuss some of the ways that builders of marine seating systems have used to allow a seated or resting posture and still maintain the spine in its optimal configuration.

Just as there is an optimal posture for a seated (or resting) human, so too is there a more favorable posture for personnel who are standing. Figure 3-10 is a graphic showing how various standing postures affect the manner in which the human body responds to shock. The data represented in the figure are transfer functions for humans in various standing postures subjected to a base excitation shock. The curves show that the most favorable transfer function occurs when the body is in a semi-crouched position with roughly a 90-degree angle at the knees. This posture allows for large displacements of the upper legs and torso (as the legs flex up and down in response to a shock event) without introducing as much shock energy into and along the skeletal path from the heels to the head. The other crouched and semi-crouched positions are the next best in terms of transfer function, with the two lock-legged postures being the worst as would be expected.

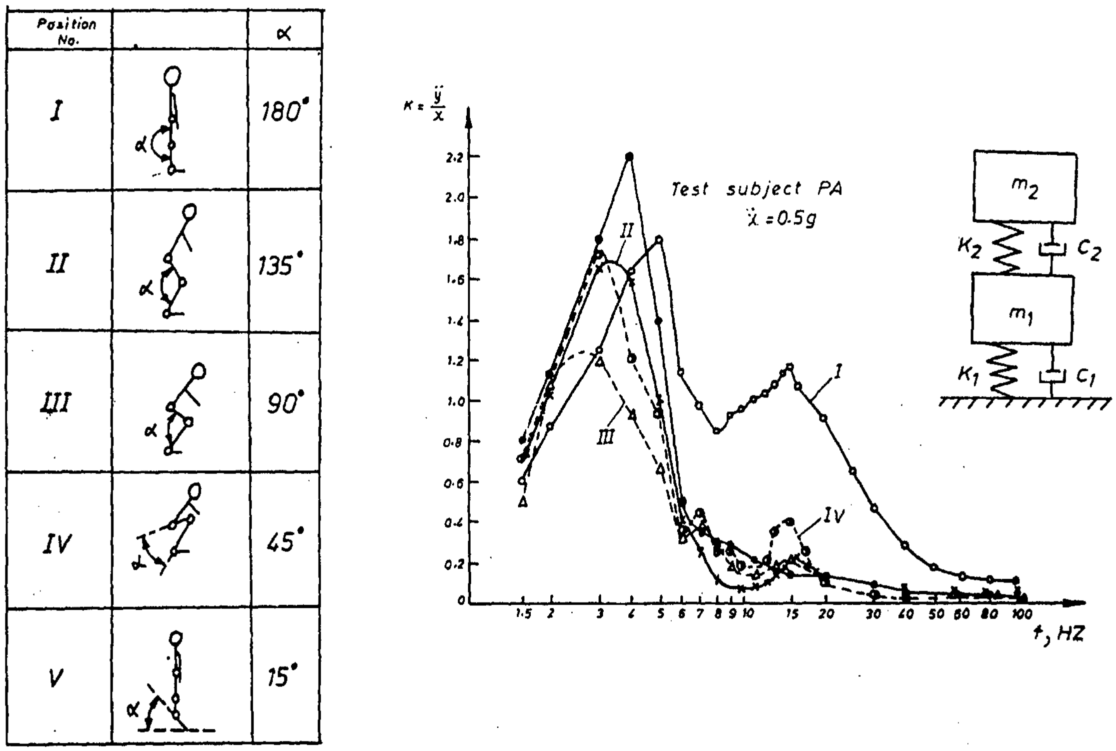


FIGURE 3-10: EFFECT OF POSTURE ON HUMAN DYNAMIC RESPONSE TO SHOCK (GHISTA, 1982)

While this data does not provide any quantitative information on injury risk, it does yield insight into the best postures for the special warfare boat occupants to assume when riding the boats in rough seas. Likewise, the range of motions needed to accommodate these postures (e.g.- large vertical motions of the legs and torso with accompanying forward motion of the knees for standing personnel) are potential design criteria for future boat designs, since there must be sufficient space for the occupants to move without striking equipment, consoles or other hard surfaces.

3.6 Ongoing and Future Injury Prediction Model Efforts

While much work has been done in the field of human biodynamics, most of the research to date has centered on human response to vibration and the accompanying discomfort and physiological effects. Relatively little work has focused directly on the type of mechanical shock exposure seen on high-speed boats. As will be discussed later, the ability of engineers and naval architects to mitigate or solve the problem of shock related injuries on the boats is hampered by a lack of knowledge about human injury limits and tolerances. Until reliable and representative models for mechanical shock injury prediction are developed, it will be difficult or impossible to develop an optimal design solution. There are several efforts, either underway or planned, which hope to address this knowledge shortfall. One such study, being conducted by the United States Army, has centered on the study of injury and discomfort among crews of tanks and armored vehicles travelling over rough terrain. This study, which is nearly complete, hopes to validate a model similar to the DRI model, but with much more versatility and applicability to various postures. Similarly, the United States Special Operations Command, in partnership with Naval Coastal Systems Station (Panama City, FL) and the University of Virginia, are working to develop human injury models that are directly applicable to the high-speed boat environment.

Chapter 4

4.0 Methods of Mitigating Mechanical Shock Effects

4.1 Overview

Before beginning a detailed discussion of shock mitigation concepts for high-speed boats, it is important to take note of the constraints placed on potential design solutions by the real world training and missions of the special warfare boats, their passengers, and crews. On first glance, the solution might seem as simple as slowing down or staying in port at night or when the seas get too rough. The reality, however, is that the critical nature of the training and missions these boat units perform, often denies them the luxury of slowing down or staying home. Similarly, one might conceptualize a shock mitigation system such as a cocoon suspended several feet off the deck by bungee cords or similar spring/damper components. Such a system would certainly provide ample displacement distance to adequately isolate the occupant from any harmful shock. Once again, the reality is that successful mission accomplishment is not possible if the crew are unduly hindered in there ability to perform their duties, and many shock mitigation concepts are simply to intrusive or constraining.

Given the constraints created by the mission requirements of the boat units and their personnel, feasible shock mitigation concepts must try to optimize the shock isolation provided without significantly impacting the ability of the boat occupants to perform their required tasks. Methods of improving ride control in rough seas (such as trim plates and deep-vee hulls) which are already well established in small boat design, will not be discussed here. Rather, we will focus on concepts which show potential for shock mitigation, but which have not yet been fully developed into mature designs.

The methods of mitigating mechanical shock effects on high speed boats can be broken down into two categories: (1) hydrodynamic, mechanical, or electro-mechanical systems, designed to reduce or distribute the shock, and (2) proper training, conditioning, posturing and monitoring of the crew and passengers on the boats. These categories will be discussed at length in the following sections.

4.2 Design Methods of Reducing Mechanical Shock to Personnel

At present we do not know enough about the exact limits and tolerances of humans below which there is little risk of injury. However, we can proceed with a discussion based on the premise that (in most cases) significant reductions in shock magnitude will also reduce the risk of injury. The next question then is what are the available means by which the mechanical shock felt by the boat occupants may be reduced. Figure 4-1 shows a summary of the various methods and locations where shock reduction and/or isolation is possible aboard these boats. Given the number of different shock mitigation methods listed, discussion of the individual methods will be broken down by their location category.

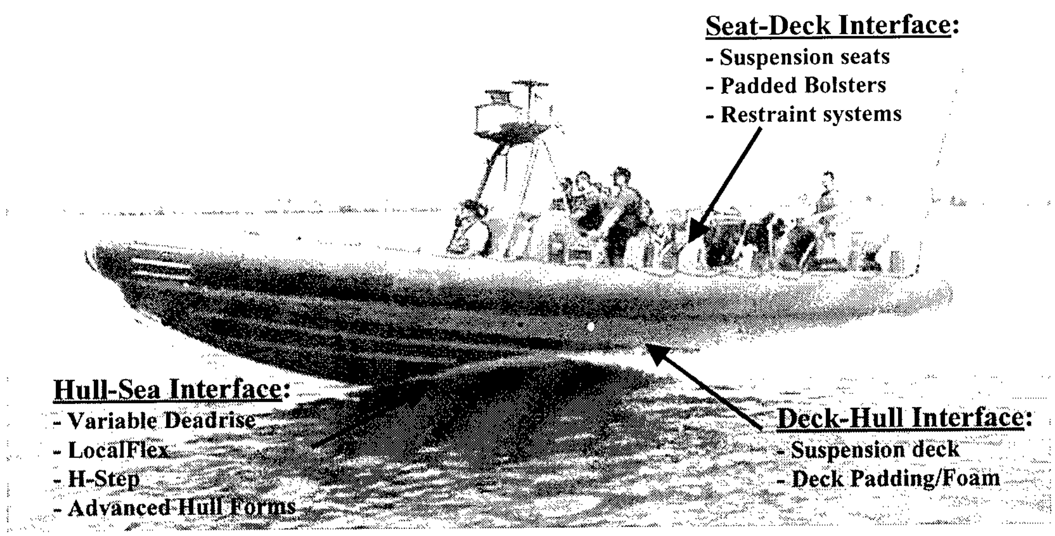


FIGURE 4-1: POTENTIAL METHODS AND LOCATIONS FOR SHOCK MITIGATION
(photo from http://www.specialoperations.com/Navy June, 2001)

4.2.1 Mitigation at the Hull-Sea Interface

Common sense would seem to dictate that the best way to mitigate the mechanical shock on high-speed boats is to do it before the shocks enter the boat at all. There are a number of shock mitigation concepts and technologies that seek to accomplish just that.

There can be any number of similar variations on a common idea, and to attempt to discuss all of them is not the intent here. Instead, representative examples of the various shock mitigation concepts are discussed along with their relative advantages and disadvantages.

Optimal Deadrise Hull

One such concept is Optimal Deadrise Hull (ODH) design. ODH seeks to find the most favorable set of deadrise angles for a hull design, to allow for desired performance while still reducing the magnitude of mechanical shock pulses from seaway interactions. Based on initial research, changes of as little as 3 degrees in hull deadrise can result in shock reductions of 12% or more, with no appreciable change in boat hull resistance (Peterson, 2000). Figure 4-2 shows the ZARN software predictions for hull acceleration and resistance at various changes in deadrise angle from the baseline.

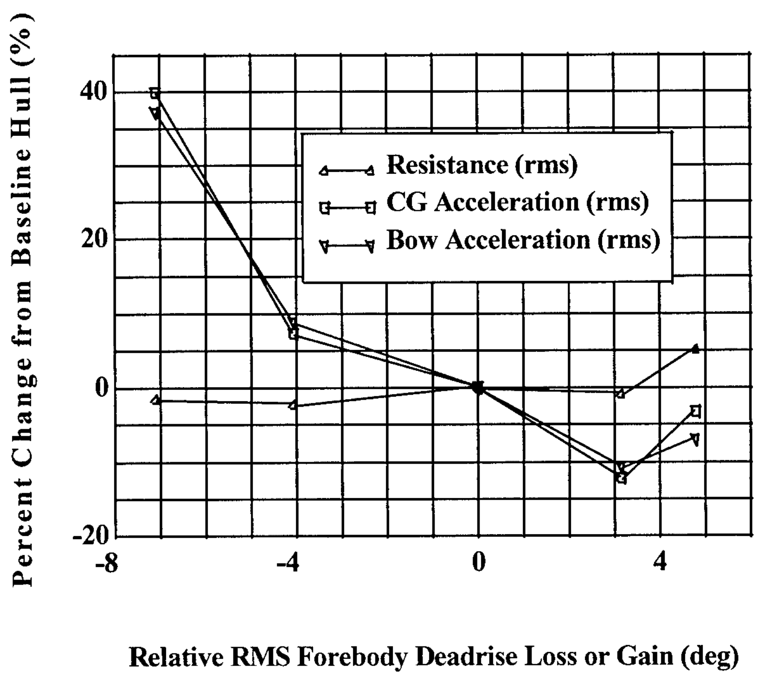


FIGURE 4-2: ZARN ODH PERFORMANCE PREDICTIONS (PETERSON, 2000)

While the size of the shock reduction from ODH is modest, it can be had with virtually no increase in boat construction cost, and without sacrificing performance. This type of concept could potentially be combined with another shock mitigation system (deck-hull, seat-deck etc.) to obtain an overall shock magnitude reduction, which is quite significant. This idea will be touched on again later.

Local-Flex®

While ODH achieves shock reduction through modifications to hull geometry, the Local-Flex® concept seeks to mitigate shock using a flexible outer hull section, which operates like a suspension system. Dr. Vorus developed the Local-Flex® system in cooperation with the University of New Orleans. Figure 4-3 shows a simple sketch of the Local-Flex® system. The system is made up of an outer Vee-hull section, hinged at both edges and at the center of the Vee. Shock isolation elements (e.g.- air bladders or similar) are located within this outer hull section so that when it flexes upward the isolation elements are compressed, absorbing energy and reducing shock. A prototype of this system was field tested in 2000, and single event shock reductions of up to 45% were obtained. However, the prototype system had no capability to "recover" to its original vee shape in preparation for successive impacts (Vorus, 1999). While an engineering solution can potentially be found for this lack of recoverability, such a solution would likely add unwanted weight and complexity to the design (e.g.- compressors, accumulators, regulators, etc.) so the feasibility of this concept for shock mitigation on special warfare craft is limited.

Hinged-Step Technology (H-STEP)

Another shock mitigation concept involving the use of an outer, moving hull section is H-STEP. Developed at Naval Coastal Systems Station in Panama City, Florida, this system uses a rigid outer hull section wedge hinged near the bow and allowed to flex against air-shocks located between the inner and outer hulls. Figure 4-4 shows a picture of the H-STEP system undergoing at sea testing.

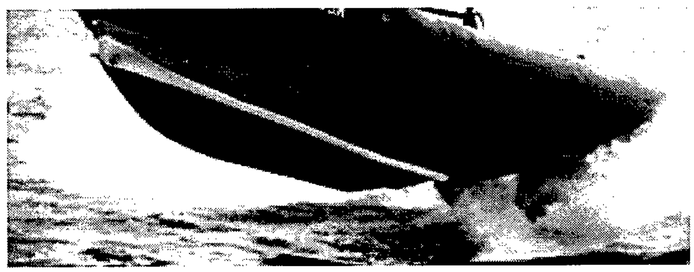


FIGURE 4-4: H-STEP SYSTEM (PETERSON, 2000)

The shock isolation elements within H-STEP were designed using the WEDIM software, which was discussed in Chapter 3. The prototype system shown in Figure 4-3 was built and tested in DATE. Testing revealed that the system provided an average of 35% reduction in shock, while increasing speed by an average of 8%. In Figure 4-5 the speed data for the boat runs (with and without the H-STEP wedge deployed).

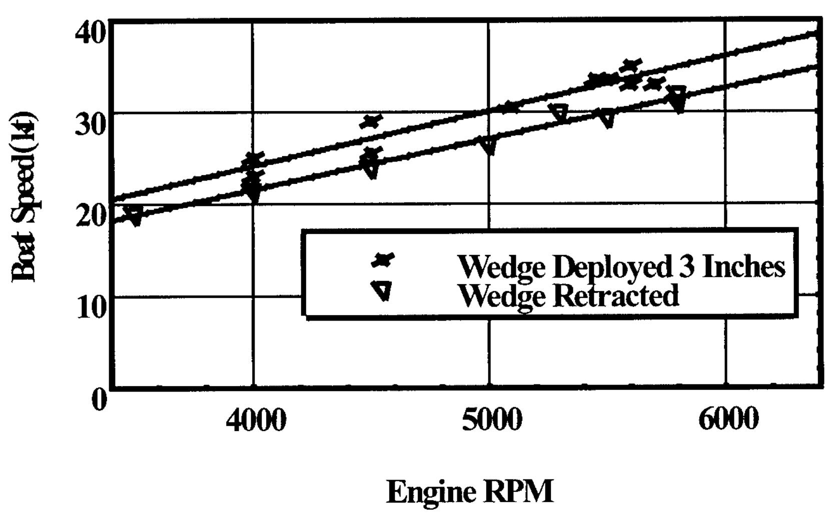


FIGURE 4-5: H-STEP SYSTEM SPEED DATA (PETERSON, 2000)

This increase in speed due to the H-STEP system could potentially be used to trade off propulsion plant weight for additional payload or other systems. Figure 4-6 shows a plot comparing the shock events measured on board the H-STEP prototype with and without the wedge deployed.

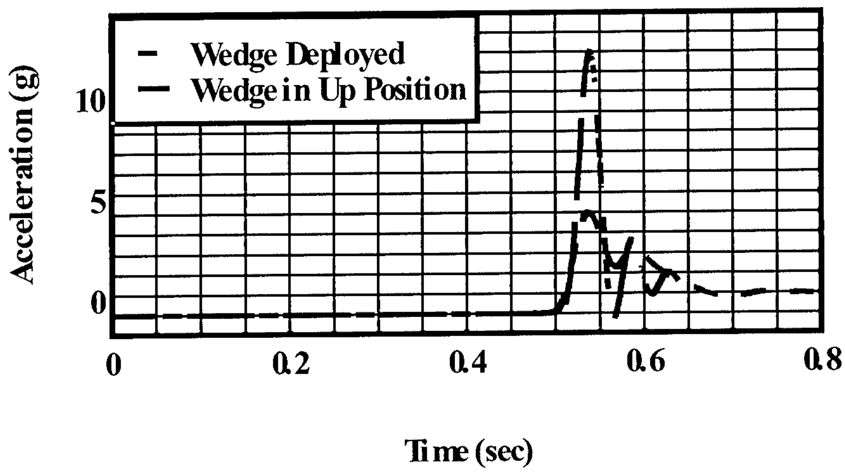


FIGURE 4-6: H-STEP SYSTEM SHOCK EVENT DATA (PETERSON, 2000)

A potential drawback of the H-STEP system, identified during testing, is its effect on the handling characteristics of the boat. This problem could well be solved with minor design modifications to the boat and its control system, but due to funding limitations, no additional research has been conducted on H-STEP at this point.

Advanced Hull Forms

While the high-speed planing hull has been the mainstay of the special warfare community for several decades, the future of high-speed boat design may lead elsewhere. Most of the work to reduce shock on special warfare boats involves research, design and testing of methods to mitigate and absorb the shocks, which occur due to wave-hull impacts or interactions. In the future, avoiding these violent wave-hull interactions all together, through the use of innovative advanced hull forms, may solve the problem. Figure 4-7 shows a summary of various hull forms in use today.

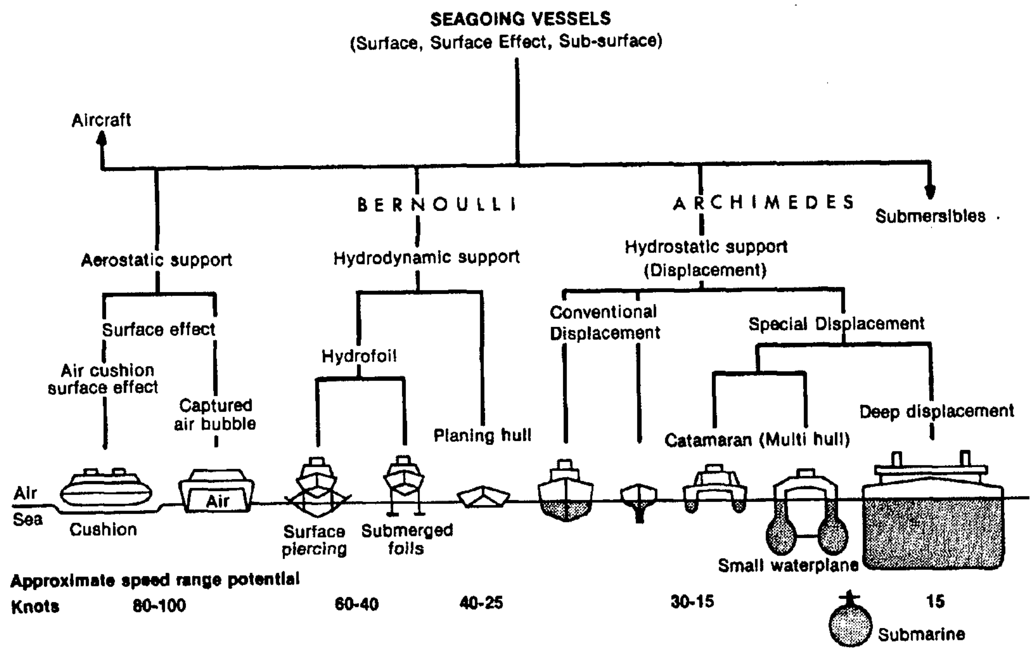


FIGURE 4-7: VARIOUS HULL FORMS (GILLMER, 1982)

Advanced hull forms such as hydrofoils and air cushions have long been used in watercraft to obtain high speeds with minimal interaction with the water surface. However, due to their limited range and payload capacities, lack of covertness, and relatively intensive maintenance and upkeep requirements, these types of vessels are not well suited for special warfare use. Other hull shapes, such as catamarans, very slender vessels (VSV), and small waterplane area craft, could potentially provide the performance needed by the special warfare community, while minimizing seaway interactions and the accompanying mechanical shocks.

Many of the new, so called "fast cat" catamarans actually incorporate both catamaran hull design and VSV or "wave piercing" hull shapes. On catamarans of this type, the payload area rides above the seaway, and is connected to dual buoyancy providing hull shapes by slender wing like uprights. These thin vertical wings cut through surface waves with little interaction and the buoyant hull sections remain mostly submerged so as not to interact with surface waves. Fast catamarans can reach speeds of over 50 knots, and smaller versions of this concept may be capable of performing special warfare missions. While many of the more advance hull forms, like SWATH (Small Water Plan Area Twin Hull), and VSV are not yet capable of satisfying the broad range of special warfare performance requirements, continuing development of these and other advanced hull concepts may eventually resolve these issues.

4.2.2 Mitigation at the Deck-Hull Interface

The most common means of mitigating shock and vibration at the deck-hull interface is through the use of rubber or foam padding (or similar cushioning material) as a deck covering. Due to the limited displacement available within these types of deck coverings, their ability to significantly reduce shocks, especially lower frequency shocks, is quite limited. For the most part, the deck coverings on special warfare boats provide vibration isolation from engine-induced vibrations, but they do not mitigate the shocks from wave impacts. Certain new cushioning materials, such as the range of products by SKYDEX®, allow a much larger variation in performance which can be designed into a deck covering of a given thickness. SKYDEX® cushions are made from plastic of varying density and durometer, formed into tiles made up of opposed hemispheres arranged in matrices such as in Figure 4-8.

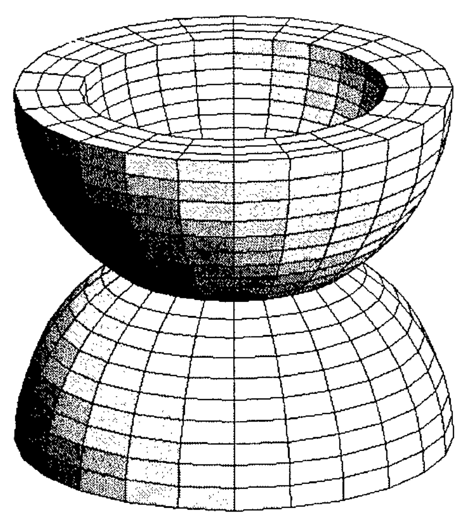


FIGURE 4-8: OPPOSED HEMISPHERE ARRANGEMENT USED IN SKYDEX® TILES (photo from www.skydex.com August, 2001)

By changing the type of plastic used, the size and shape of the hemispheres formed, and the arrangement of these hemispheres in the tile matrix, a wide range of shock and vibration isolation performance is achievable. Among their other uses, SKYDEX® products are currently used as liners in football helmets, as inserts in sneaker soles, as cushions on snowmobile seats, and to surface playgrounds in order to prevent injury to children who accidentally fall from playground equipment such as jungle gyms. The suitability of SKYDEX® cushions as deck coverings on special warfare boats is discussed in detail in Chapter 5.

Perhaps the best way to achieve significant shock mitigation at the hull-deck interface is through the use of a suspended deck or cockpit section. The concept of suspending the passenger compartment of vehicles is well established in the automotive and agricultural equipment industries, but it has not yet been well developed for application in the marine industry. As discussed at the beginning of this chapter, one of the biggest limitations on mitigating shock is the amount of space available for displacement between the area where the shock originates and the area being protected. For many boats, the area between the deck and the hull offers the most available displacement room. Designers at SafeBoats, a boat builder in Port Orchard, Washington, have stated that they can accommodate up to 12 inches of downward deck displacement in their line of aluminum hulled planing boats. Figures 4-9 and 4-10 show examples of how much shock reduction is possible with a passive shock isolation system having roughly 12 inches of available displacement. The graphs in Figure 4-9 and 4-10 were generated with a single degree of freedom, mass-spring-damper model (like the one shown in figure 2-7), using the convolution integral and base impulse excitation (Kausel, 2001 and Rao, 1995). The figures shown are for a system with a natural frequency of 2 Hz and a damping ratio of 0.35. These values put the system response well below any natural resonance of the human body. The MATLAB script for this model is located in Appendix B. While a complex, non-linear model would provide better more accurate predictions, the simple model used here is sufficient for estimating system performance in order to determine the feasibility of further study.

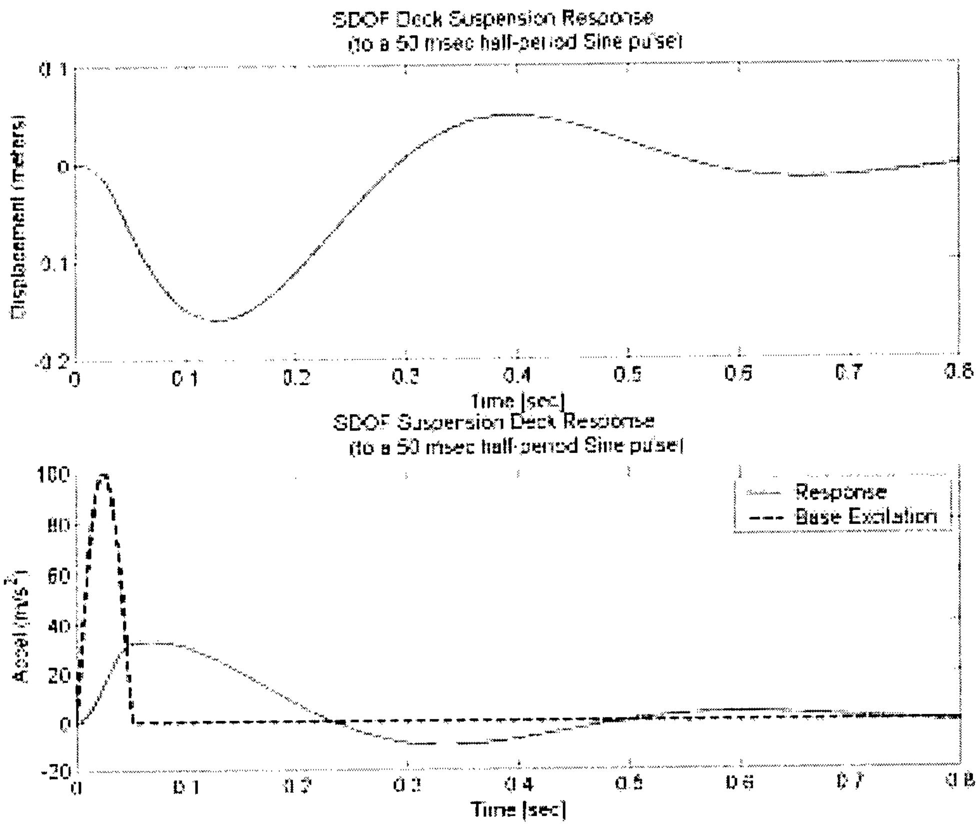


FIGURE 4-9: MODEL PREDICTION FOR SUSPENSION DECK (50MSEC SHOCK PULSE)

This first graph is for a shock event of 50 milliseconds with peak acceleration of 100 m/s^2 simulated as a half sine wave pulse. As was mentioned in Chapter 2, these values are similar to those measured for large magnitude shocks on the boats themselves. As the figure shows, the model predicts a potential 67% reduction in the shock pulse magnitude for this case.

While many of shock events measured on special warfare boats are approximately 50 milliseconds in duration, longer duration shock events are common, and this affects system response as the next figure shows.

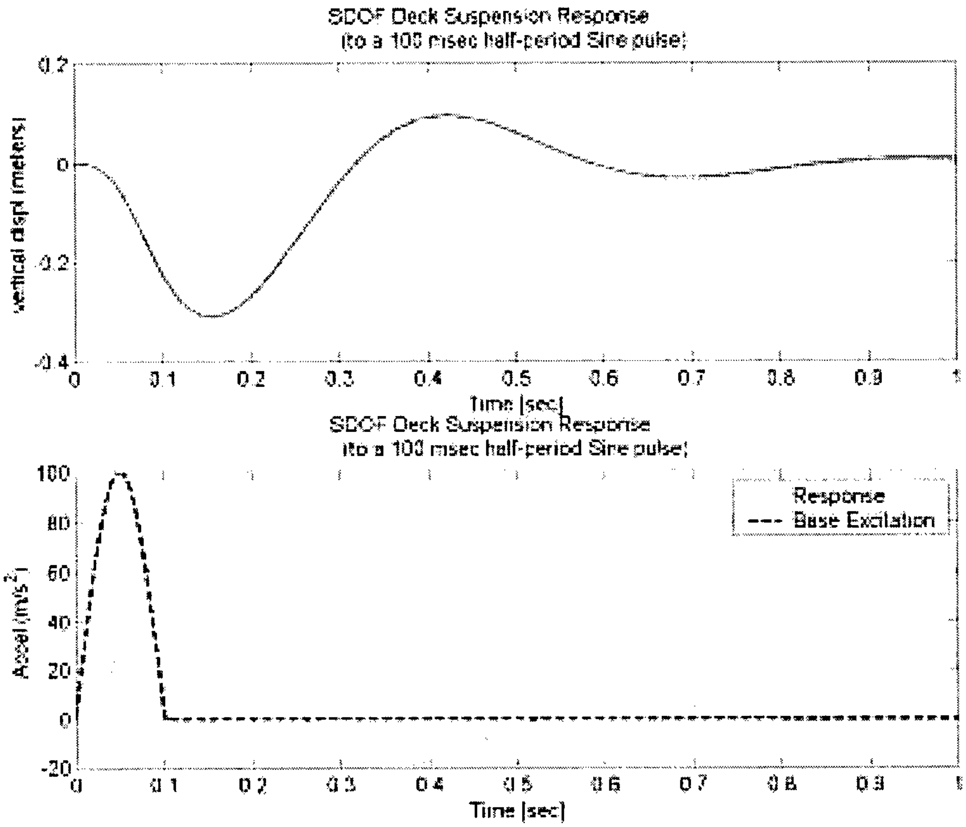


FIGURE 4-10: MODEL PREDICTION FOR SUSPENSION DECK (100MSEC SHOCK PULSE)

In this case, with a 100-millisecond shock pulse, the model predicts just over 35% reduction in shock magnitude with similar response frequency. The most noticeable difference, however, is in the displacement, which increased from roughly 6 inches to just over 12 inches. In a real suspension system, the damping could be made adjustable so that for changing sea states etc. the damping could be tuned for optimal shock mitigation without bottoming out.

Although the large displacement available with a suspended deck concept allows for significant reduction in shock magnitude, equally important is the low natural frequency of such a system. In fact, as discussed in Chapter 4, the human body behaves as a solid mass at excitation frequencies of 2 Hz or less, so there would be no amplification of forces due to human body transmissibility at these frequencies. Likewise, the body is able to maintain visual contact and focus on objects (both near and distant) while undergoing vertical oscillations of 2 Hz or less. Another advantage of suspended decks or cockpits is that control consoles move up and down with personnel, allowing unimpaired operation. Other shock isolation concepts that are not able to operate at such low natural frequencies must address concerns about exciting natural frequencies of the human body and potentially increasing the risk of injury from a given shock event even though the magnitude of the shock is reduced. Similarly, if a shock mitigation concept involves relative motion between personnel and their consoles (e.g.- suspension seats) the ability to properly operate the boat and its systems is impaired.

Continental Controls and Design in San Pedro, CA has done some preliminary design and prototype testing on suspension deck concepts, which is discussed in Chapter 5. Retrofitting existing special warfare boats with suspension decks or cockpits would not be cost effective or operationally feasible, but incorporating this concept into the next generation of boats is an option worth exploring.

4.2.3 Mitigation at the Seat-Deck Interface

The majority of research and development by the maritime industry, in the area of shock mitigation to personnel, has centered on seating systems. Typically in past high speed boat designs, the boat's hull geometry, size, weight, speed and performance characteristics were already "locked in" before any significant thought was given to shock mitigation or crew comfort. In situations like this, the (feasible) options available for achieving mitigation of shock effects are limited to seating concepts, ergonomics, restraint and support systems, cushioning deck surfaces, and operational factors such as crew fitness and boat operator training. The range of seating and support concepts can be roughly divided into three categories: 1) Conventional style seating, 2) Standing bolsters and 3) Non-conventional style seating.

Conventional Style Seats

For our purposes, conventional style seats will be defined as seats which support the body with upper legs in a horizontal position and the torso in a vertical or near vertical position, with the lower legs approximately vertical as well. This is the standard type of seating seen on most commercial boats. This type of seating has the advantage of being well researched and developed by many industries and we as humans are conditioned to using this style of seat in our daily lives. The disadvantages of this seating, however, are that it puts the lumbar-pelvic region in a non-optimal position for sustaining shocks and it denies the body the use of its legs for shock absorption. Despite the drawbacks of the conventional seated position for withstanding mechanical shock, many seat designs have been created which are effective at protecting personnel from certain types of vibration and shock exposure.

One way in which conventional seats try to aid the body in withstanding mechanical shock is by positioning the body and distributing the shock so that it is not so concentrated on a specific point or region in the skeleton-muscular system. The STIDD Model 800v4 seat currently in use on the MkV SOC employs this method. Through the use of a 4-point harness, a reclining backrest, arm supports, and biomechanical seat cushions and bolsters, the STIDD 800v4 allows shock forces to be distributed over the thighs, upper and lower back, shoulders and forearms. When properly employed, this arrangement reduces the intra-spinal stresses from shock events and, for shocks of 3 to 4 Gs in magnitude, it can be effective in preventing spinal injuries (Townes, 2001).

There are, however, legitimate concerns involved with static seat concepts such as the STIDD 800v4. The distribution of shock related stress from the back to other areas of the body might result in a situation where you are robbing Peter to pay Paul. For instance, the human shoulder complex is not a load bearing joint and using the shoulders and forearms to take stress off the spine may lower risk of spinal injury while increasing the risk of shoulder injury. Also, since this type of seat does not actually reduce the incoming shock, the internal organs of the body are still subjected to the full magnitude of the shock pulse. Long-term effects of shock exposure to soft tissues are not well understood. However, the occurrence of near term effects, such as micro-tears (and accompanying blood in urine) in the kidneys and other organs, have been documented (Griffin, 1990) and suggest the potential for long term effects on soft tissues as well.

The majority of prior work on suspension seat development was conducted by the automotive and agricultural industries in an effort to protect truck and tractor operators from prolonged exposure to shock and vibration. Figure 4-11 shows a schematic drawing of a PPG suspension seat developed for agricultural tractors in Europe by the Patil & Ghista group.

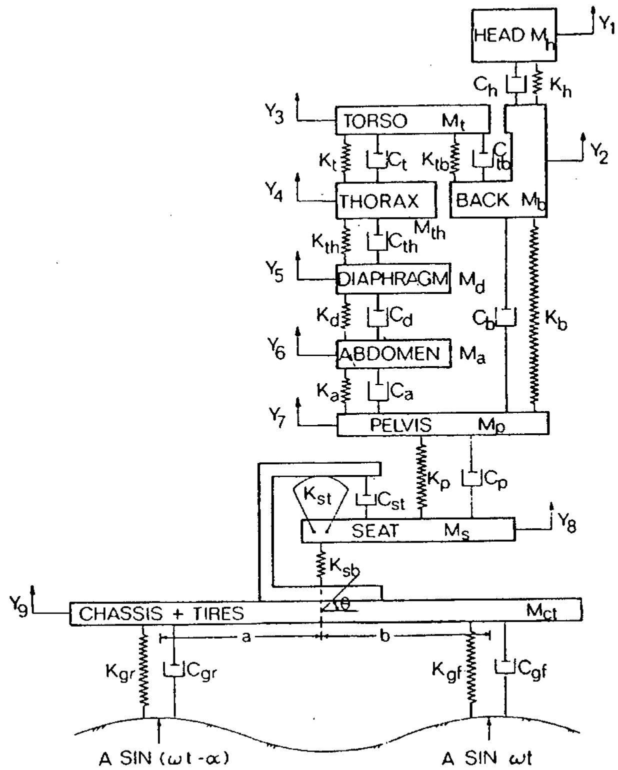


FIGURE 4-11: PPG SUSPENSION SEAT SCHEMATIC (GHISTA, 1982)

This seat uses a lower coil spring opposed against an upper leaf spring and damper and it is very effective at isolating the operator from shocks of 1 to 2 Gs in magnitude (Ghista, 1982). While there are many different suspension seat designs in production, the acceptable limitations for vertical seat displacement (roughly 4 inches), size, weight, and cost put an upper limit on performance. Figure 4-12 shows the transmissibility curves for six different seats, five of which incorporate some type of spring-damper suspension element (all but seat F). One such suspension seat design, the STIDD model 800v5 (the suspension version of the STIDD 800v4 seat) was tested during this project (Chapter 5).

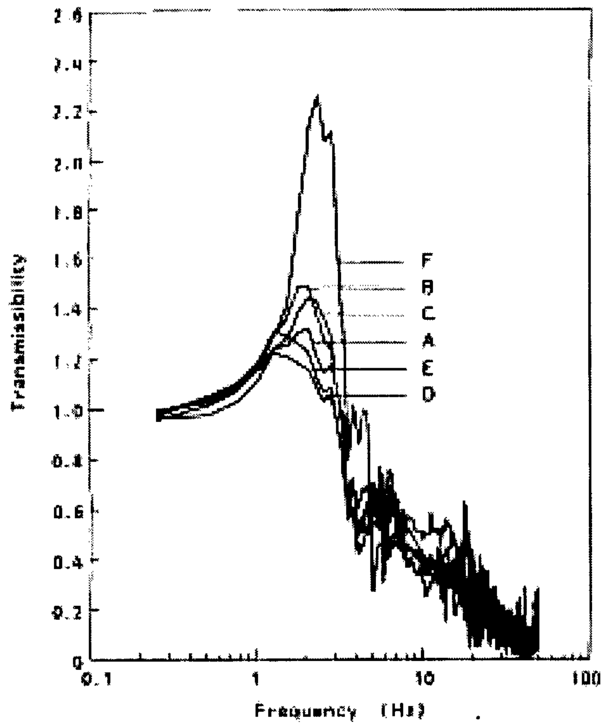


FIGURE 4-12: SUSPENSION SEAT TRANSMISSIBILITY CURVES (GRIFFIN, 1990)

In this figure, seat F is a metal seat with foam cushion. The remaining seats incorporate various spring-damper suspensions. The performance of the five suspension seats (A thru E) is quite similar. The suspension seats provide good transmissibility at frequencies above 4 to 5 Hz and have damped resonant frequencies between 2 and 3 Hz. The performance indicated by these transmissibility curves is quite good, but it does not give any information on a vital area of performance... the maximum suspension displacement, and maximum shock which can be absorbed without "bottoming out" the suspension. Most significant shock events seen on special warfare boats correspond to frequencies of 5 Hz or more, for which these seats appear to provide very good reduction. However, the larger the magnitude of the shock, the larger the displacement that is needed for the suspension system to operate as designed. For a shock event where the seat does not have sufficient travel range to operate properly, the seat will “bottom out” and a very abrupt shock will be transmitted to the occupant by this impact. So, while suspension seats can provide good shock isolation performance up to the limit of their available travel, for many of the larger magnitude shocks experienced on special warfare boats they may actually amplify the shock transmitted to the occupant unless they are designed with sufficient travel length. The available travel length is constrained by the size and geometry of the boat cockpit as well as the ability of the crew to perform their duties effectively. Very large seat motions may cause seat occupants to be moved away controls or consoles or may hamper their view out of the boat. This is just one of many design trade-offs which must be considered when working to solve the shock exposure problem.

Standing Bolsters

Another type of seat/support used on high-speed boats is standing bolsters. For our purposes, bolsters will be defined as any support, which acts to constrain the occupant in the lateral or longitudinal directions. These types of support typically involve a padded backrest against which boat occupants can lean while sitting or standing, as well as padded side sections, which support and restrain the occupant against lateral motions. The NSW RIB utilizes standing bolsters exclusively (with a short fold out section for resting on in calmer seas), while the STIDD 800v4 seats on the MkV SOC provide the capability of lowering the seat pan down to convert from conventional seats to standing bolsters. A photo of the standing bolsters used on the NSW RIB is shown in Figure 4-13, note the backrest pad and the side shell. While these are primarily standing bolsters, they have a small fold-out half seat which can also be seen in the figure. Another item to note with this particular bolster is the minimal amount of padding. This lack of padding, especially on the side bolsters, makes the seat quite uncomfortable and does not provide good lateral restraint since the occupant is not "wedged" into the bolster. In this situation, the occupants are merely standing between the side bolsters so that when a lateral shock occurs they are first struck by one side of the bolster and forced across to impact with the other side. This can result in severe whiplash of the head-neck complex and also puts added stress on the arms and shoulders as the occupant attempts to arrest their motion. With better bolster padding, the occupants are restrained against this ping-pong motion and are better able to control their response with arms and legs.

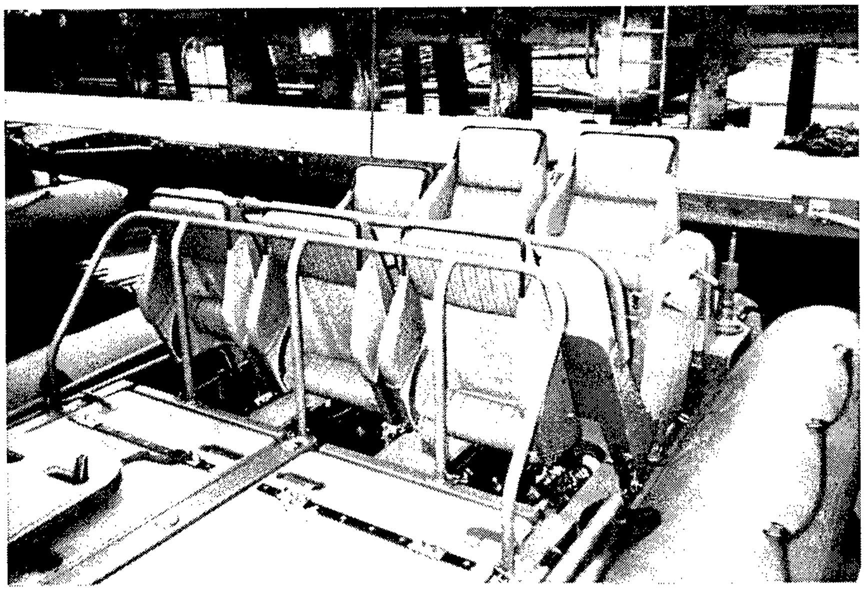


FIGURE 4-13: NSW RIB STANDING BOLSTERS

One obvious advantage of the standing bolster design is that it allows the use of the legs for shock absorption. Another advantage is that the spine is typically in a better geometry for withstanding shocks when it is in a standing (with knees bent) posture. As discussed in Chapter 3, standing with knees bent at about a 90 degree angle puts the body in a posture for minimal transmissibility in the vertical direction. The basic shape of standing bolsters effectively prevents the incorporation of a suspension system. However, deck-cushioning material (such as SKYDEX mentioned previously) can aid in reducing shock to the knees and ankles, which do not benefit from the shock absorption provided to the rest of the body by the legs.

Like conventional seats, standing bolsters also have their drawback. Poorly bolstered designs, such as those on the NSW RIB, do not firmly secure the occupant against lateral motions. This can result in whiplash movement as the body is thrown to one side or the other and then comes up hard against the sides of the support. The neck injury rate on the NSW RIB, much higher than that of the MkV SOC, is largely the result of severe lateral and longitudinal shocks. Another drawback is the stress placed on the hands, wrists and shoulders as occupants hold on to handrails etc. to brace themselves against shocks and other motions. Similar to neck injuries, occurrence of shoulder, wrist and hand injury is higher for personnel on the RIB than those on the MkV SOC. A third drawback of standing bolsters is that in order for the occupant to utilize their legs to absorb shock, there must be sufficient room for their knees and legs to flex down and forward. The NSW RIB (especially for the boat crew itself) provides very limited room. This limits the occupants to two options: 1) Abbreviating their motions (and thus absorbing less shock) or 2) Risking serious injury from striking knees etc. on consoles or other hard surfaces. A final disadvantage of bolster supports is that the fact that they do rely on the legs to absorb shock. Over periods of extended shock exposure, especially for personnel who are not in good physical condition, fatigue greatly reduces the ability of the legs to effectively absorb shock. Many of the injuries experienced by boat personnel occur during the later portions of the training or mission, which is primarily the result of fatigue.

Non-conventional Seating

There have been some quite successful attempts to design and build seating systems, which address some of the drawbacks of the previous seating/support concepts discussed. One such design, the Ullman seat, or "jockey" seat, has performed well in preliminary testing by the U.S. Navy (Chapter 5) and is currently in use by several European navies and coast guards. The Ullman seat, shown in Figure 4-13 and 4-14, combines the natural ability of standing humans to absorb shock with their legs, with the added capability of a seat suspension. The saddle style seat provides allows for good lateral support with the thighs and additional upper body stability is supplies by the handlebars.

FIGURE 4-14: ULLMAN SEATING SYSTEM (photo from www.ullmans.com JULY 2001)

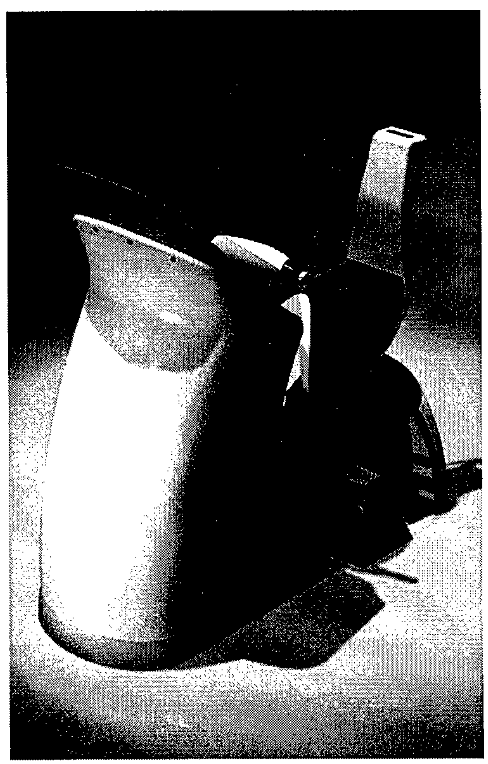


FIGURE 4-15: ULLMAN COCKPIT (photo from http://home.swipnet.se/rib-world JULY 2001)

In operation, the Ullman seat works very similar to a motocross bike. The occupant stands in the stirrups, up above the saddle in a semi-crouched position (e.g.- knees at or near 90 degrees as mentioned earlier). The upper body is positioned above the seat, with hands holding on to the handlebars. When the boat is about to impact a wave or the ocean surface, indicated visually and by the sensation of free-fall, the occupant rises up slightly (thus providing greater travel distance for shock absorption by the legs). As the impact occurs, the occupant begins to move downward with the legs absorbing the first part of the shock. When the occupant contacts the saddle, the saddle suspension (along with some action by the legs) provides the rest of the shock absorption. This arrangement provides a large degree of motion for shock isolation, while still allowing the occupant to rest on the saddle during periods of calm seas or low speeds, which reduces fatigue. The incorporation of the Ullman cockpit (or similar design) integrates the steering and throttle controls with the handlebar supports. This allows the boat operators to maintain positive control of the craft despite the large vertical motions they are undergoing. Although the Ullman seat can potentially provide better shock mitigation than other seating/support systems, it still lacks the complete acceptance of special warfare boat drivers and crews. One major reason for this is that the occupant often has the perception that they are more exposed and less well secured in the boat when riding in an Ullman seat. Other concerns include the ability to effectively monitor gauges, operate radar screens and other control consoles, and employ weapon systems, while undergoing the large vertical motions associated with this seat. Finally, there are concerns about the ability to safely "get off the horse" while underway, in order to move about the boat to perform other tasks.

4.3 Operational Methods of Reducing Mechanical Shock to Personnel

While the previous section discussed design solutions for mitigating shock and shock effects, this section will briefly address ideas related to personnel training, fitness and shock exposure management. Although the emphasis of this report is on identification, testing and evaluation of engineering design solutions, there are several less technical ways to address this problem and they are worth mentioning here.

Physical Conditioning

Simply put, the better physical condition a person is in, the better able they are to withstand prolonged exposure to the physically demanding environment found on special warfare boats at sea. As stated previously, the body's ability to absorb shock (with legs, etc.) becomes impaired as the body becomes fatigued. While special warfare personnel already undergo excellent physical conditioning, this physical training can be better tailored to the special needs of the mechanical shock exposure environment. Specifically, training regimens such as those used by world class downhill and mogul skiers can be borrowed from to better train and condition the legs for endurance and shock absorption.

Personnel Training

The safest small boat design in the world can still cause injury to its occupants if it is not operated properly. The boat driver's skill has a significant effect on the ride quality on high-speed boats. Slight changes in boat speed, direction and attitude have dramatic effects on the magnitude and frequency of impact shocks received. Understanding and acknowledging the limitations of the boat, its occupants, and equipment, will also allow the operator to slow down (within the limits of the mission requirements) to minimize impact severity. While boat unit coxswains receive regular training, the nuances skilled of boat driving are not always easily adopted. Other factors, such as operations at night or in inclement weather, impair the boat driver's ability to see, and thus prevent proper throttling and steering of the craft to minimize impacts.

Another important topic for training is the proper way to stand, sit, and move about the boats while underway. Proper understanding of how to use the various seating and support systems is necessary for these devices to work properly. Understanding the postures that provide the human body its best ability to absorb shock is also vital.

Exposure Control

The link between prolonged mechanical shock exposure and injury is well established qualitatively if not quantitatively. Effective management and control of personnel exposure to mechanical shock can potentially prevent or minimize the risk of injury. While it may not be possible to directly correlate shock exposure to injury risk, certain injury models (such as DRI) are available for use. Measurement of shock exposure to boat unit personnel while underway can provide early warning of an impending injury. This exposure can be measured by instrumenting the boat hull, the seats/supports, or better yet the individual personnel. When a predefined threshold of exposure has been exceeded, the boat crewman can be pulled from the boats for the number of days or weeks needed to let the body recover without risking injury from cumulative effects. While no comprehensive data collection system is currently available for this application, the technology to create such a system certainly exists.

Exposure control extends beyond simply monitoring and managing exposure while on the boats. The effects of shock exposure are cumulative and can result from any shock exposure, not just that found on the boats. Simply jogging or running for physical fitness exposes the runner to shocks of up to 1-2 Gs at the rate of 120 per minute or more. It is not a far stretch to assume that personnel assigned to boat unit duty should avoid high impact fitness regimens and instead use low or no impact fitness options such as swimming, biking, rowing machines and similar low impact exercise machines.

Chapter 5

5.0 Testing and Evaluation of Shock Mitigation Systems

5.1 Overview

In order to properly design and fabricate optimal shock isolation systems, an effective means of testing and evaluating the design is required. While theory and numerical modeling can go a long way in predicting performance, non-linearities in shock isolation components, excitation shock events, and human body response, make exact model predictions difficult or impossible. Testing of shock isolation concepts under real world (or nearly real world) conditions provides invaluable information on system performance, which can be used in an iterative manner to obtain an optimal design. The essentially two general methods for testing shock mitigation systems for high-speed boats: 1) At-Sea Testing and 2) Laboratory Testing. This section will discuss the use of both of these methods, with their associated advantages and disadvantages. The validation of drop table testing for shock isolation system evaluation will be discussed at length.

5.2 At-Sea Testing

Although at-sea testing is often more costly and inconvenient than lab testing (in terms of equipment, manpower, facilities etc.) it has historically been the more readily accessible means of testing since the squadrons of special warfare boats (and similar test boats) are already available. At-sea testing can be as simple as installing a new seating system on a boat and taking it out to sea to get the boat crew's qualitative opinion on its performance with no specific regard to the existing sea state, boat speed etc. At the other extreme, at-sea testing can involve thorough instrumentation of the boat, isolation system, and crew, with the incorporation of high-speed video recording and precise measurement of wave heights, weather conditions and boat speeds and directions. Additionally, at-sea testing can be done on a single shock isolation concept, or a side-by-side comparison of two or more different concepts can be performed. The use of the side-by-side comparison method helps to address the difficulty of repeatability in at-sea testing. Since both systems are being tested simultaneously, their performance can be compared (within the scope of the existing shock environment) to determine both qualitatively and quantitatively which system performs better.

Naval Coastal Systems Station (NCSS) in Panama City, Florida, recently conducted a successful 3-day at-sea test using a RIB style test platform (Peterson, 2001). This test involved a side-by-side comparison of the Ullman "jockey seat" and the STIDD Model 800v4 seat currently in use on the MkV SOC. In order to best ensure that the two seats were subjected to similar shocks, they were located laterally adjacent and at the same longitudinal position in the boat as seen in Figure 5-1 below.

FIGURE 5-1: AT-SEA TESTING ARRANGEMENT OF STIDD AND ULLMAN SEATS (PETERSON, 2001)

Although it is difficult to obtain a high degree of repeatability during at-sea testing, the NCSS test was able to achieve some degree of repeatability for a portion of the testing by jumping the wake of a 135ft YDT-18 dive boat. The dive boat, operated at constant speed and heading in otherwise calm water, was able to generate a consistent wake wave for the test boat to jump. By jumping the wake at the same speed and heading, the generated shock events were roughly similar. This wake crossing method also allowed testing to be conducted on days when calm seas would otherwise have prevented any useful data collection. During the test the boat was also operated in the Gulf of Mexico, during periods of rough seas, to provide test data during realistic seaway conditions (Peterson, 2001).

During the NCSS test, the seats were evaluated both qualitatively and quantitatively. The qualitative assessment was accomplished using high-speed video of the seats and their occupants, as well as questionnaires on ride quality answered by the seat occupants. Quantitative evaluation was performed using acceleration measurements at the boat deck, both seat pans, and on the hips of both seat occupants. During the test, the STIDD 800v4 seat, which has no inherent shock mitigation system, was used in its standing bolster mode, while the Ullman seat operated in the manner described in Chapter 4. Experienced boat operators were used in both seats, and these operators alternated between seats to allow them to compare the relative performance (Peterson, 2001). "The desired next step, to predict the possibility or probability of discomfort and injury for the occupants in the two positions using established discomfort and injury models and standards, was not possible because the required discomfort and injury standards for occupants in complex standing positions do not exist (Peterson, 2001)." However, it is generally agreed that the lower magnitude shocks experienced by occupants of the Ullman seat do equate to some degree of reduced injury risk. In any event, this test illustrates the amount of time, manpower, equipment and other resources, which are needed for successful at-sea testing.

5.3 Laboratory Testing

While laboratory testing has been extensively used in the design and development of shock isolation systems in the electronics, and transportation industries (as well as many others), it has not yet been used to full advantage to address mechanical shock effects on special warfare boats. One of the main goals of this thesis was to develop and validate a reliable and relatively inexpensive method of laboratory testing for the design and evaluation of shock isolation systems for high-speed boats. Figure 3-1 showed the range of different machines and devices that can be used for shock and vibration testing. Based on the relative capabilities and limitations of the various shock testing machines

(Chalmers, 1996), a drop table apparatus was chosen for use. Figure 5-2 shows an example a drop table arrangement.

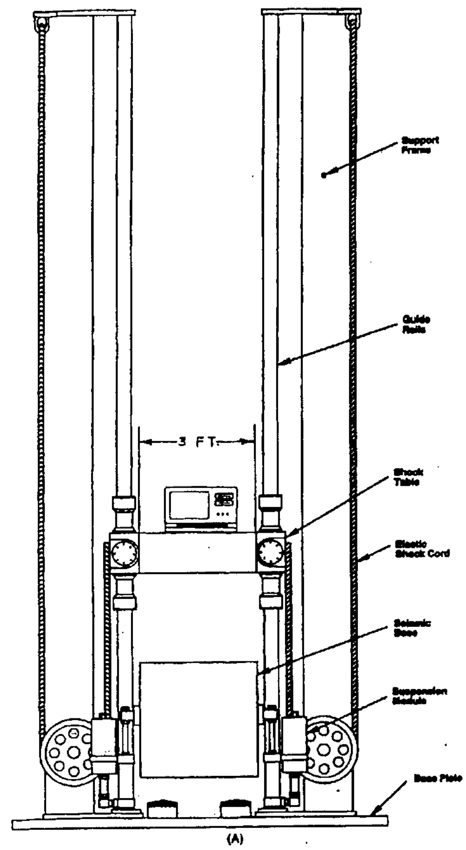


FIGURE 5-2: EXAMPLE OF A DROP TABLE TEST MACHINE (CHALMERS, 1996)

Drop tables are typically single-degree-of-freedom devices, which consist of a stiffened platform or "table" (to which the system to be tested is attached), guide rails, and some means of raising and releasing the table or platform. The drop table can either be allowed to fall under the acceleration of gravity, or if necessary it can be pushed or pulled downward at higher accelerations in order to produce larger magnitude shocks. When it reaches the bottom of its motion, the drop table strikes the base or "anvil" generating the shock pulse. By introducing materials of different shape and physical properties between the table and the anvil, a wide range of shock pulse shapes and magnitudes can be obtained. This wave shaping material hereafter referred to as the moderator, can be lead cones or spheres, foam padding material, or any number of other cushioning or energy absorbing shapes and materials. By dropping the table from the same height onto the same type of moderator, highly repeatable shock pulses can be generated. Once the behavior of a given table and moderator are known, the drop height and moderator size/shape can be fine-tuned to achieve a specific desired shock pulse.

In order to reproduce shock events with similar magnitude and shape of those experienced on the boats, a simple gravity drop table was deemed adequate. Figure 5-3 shows the simple vertical axis drop table apparatus fabricated for this study.

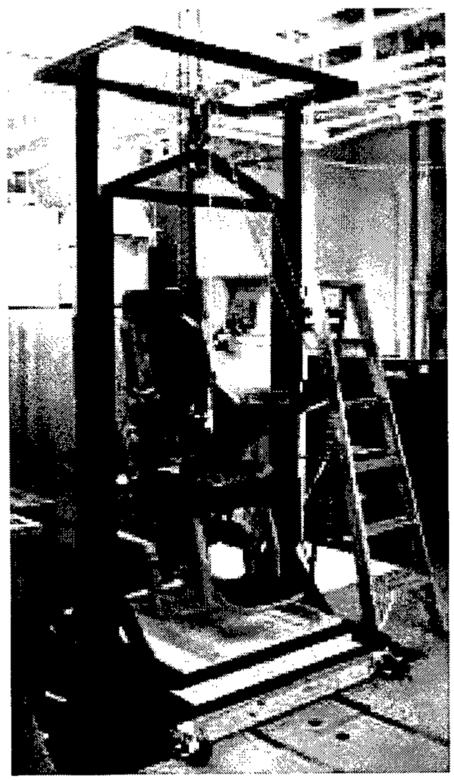


FIGURE 5-3: DROP TABLE WITH STIDD MODEL 800V5 SEAT MOUNTED FOR TESTING

It consists of a reinforced steel frame drop table, guided and constrained by an arrangement of vertical steel posts and sleeves. The table section is raised using a 1-ton chain-fall hoist, and a lifeboat quick release hook was adapted for use in dropping the table.

SigLab® Version 2.13 (marketed by DSP Technology Inc.) was used to record and process accelerometer data from the drop-table. ICP® piezo-electric accelerometers, made by PCB Piezotronics, Inc. provided the inputs to SigLab®. The SigLab® system consists of a fast fourier transform (FFT) box and PC software which operates on top of the MATLAB® software application. The system can function as a conventional oscilloscope, network analyzer, spectrum analyzer, or signal generator, with a variety of sampling, averaging and filtering options. The SigLab® system, with Dell laptop, FFT box, PCB signal conditioners, and ICP accelerometers, is shown in figure 5-4. Equipment specification documents and calibration certificates for this system are located in Appendix D.

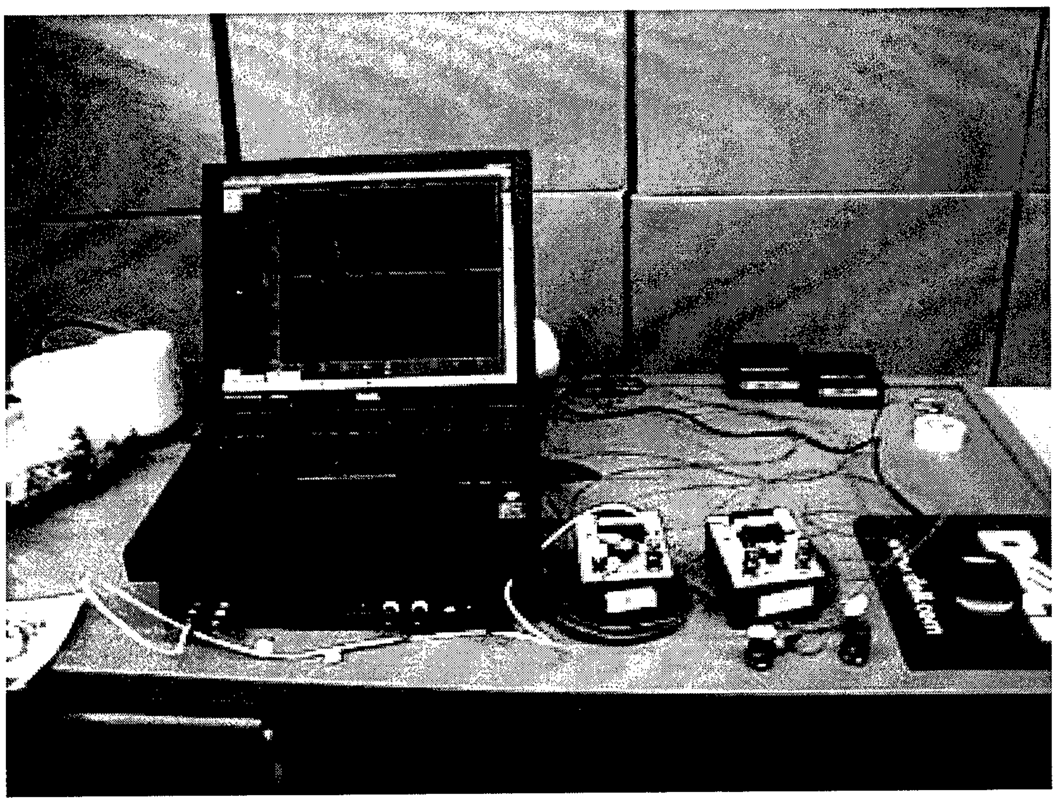


FIGURE 5-4: SIGLAB® DATA COLLECTION AND PROCESSING SYSTEM

A variety of moderators were tested to obtain the desired magnitude and shape shock pulse. Figure 5-5 shows examples of the shock event waveforms obtained from some of the moderator-drop height combinations.

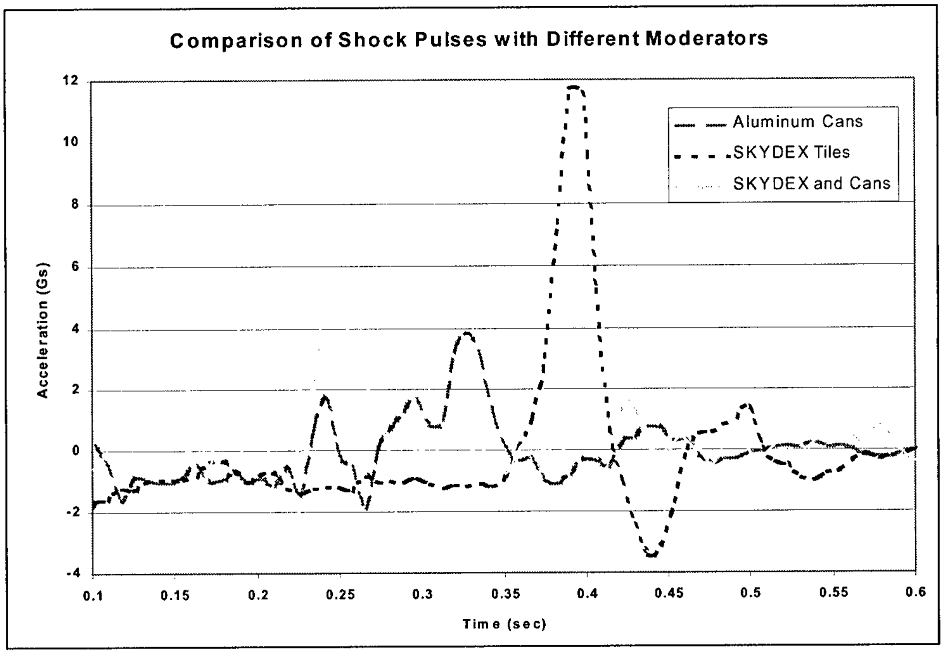


FIGURE 5-5: COMPARISON OF SHOCK PULSES SHAPES OBTAINED FROM VARIOUS MODERATORS

SKYDEX® tiles were chosen for use as the wave-shaping moderator. Figure 5-6 shows some shock event waveforms obtained using the SKYDEX® tile combinations.

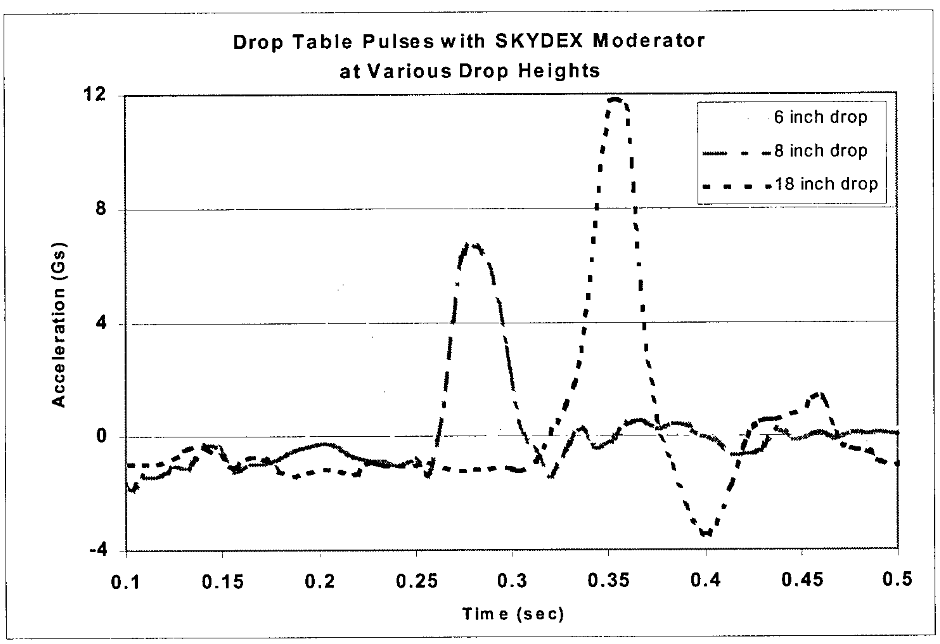


FIGURE 5-6: SAMPLE DROP TABLE SHOCK EVENTS USING SKYDEX TILES AS MODERATOR

By varying the type of tile (density, durometer and geometry), as well as the arrangement of the tiles (single vs. double stacked, etc) a wide range of shock pulse shapes was obtained. As the figure shows, these shock events range in magnitude from roughly 5 to 12 Gs with durations of roughly 40 to 60 milliseconds. These numbers are representative of a majority of the shock events seen on special warfare boats. The drop heights used to generate these shock pulses ranged from 6 inches to 18 inches. Assuming the drop table accelerates downward at the acceleration of gravity from the moment of release until impact, the velocity at impact is given by:

$$\text{Impact Velocity (v)} = \sqrt{2gh} \tag{5.1}$$

Assuming the impact acceleration time history $(\ddot{y})$ is a half sine wave pulse described by $(\ddot{y} = A\sin(\frac{2\pi t}{\tau}))$ over the half period $(\frac{\tau}{2})$, then the peak acceleration caused by an impact velocity (v) is given by:

:

$$\text{Peak Acceleration} = \frac{v\pi}{\tau} \tag{5.2}$$

Figure 5-7 shows the expected impact velocities and peak accelerations for a range of drop heights and shock pulse widths.

Drop Hgt (inches)	Impact Shock Pulse Duration (milliseconds)		
	40	50	60
6	6.92	5.95	4.59
8	7.99	6.39	5.33
12	9.79	7.83	6.52

FIGURE 5-7: PREDICTED PEAK ACCELERATIONS (IN GS) FOR HALF SINE WAVE SHOCK PULSES

Note that the actual peak accelerations generated by the drop table are higher than those predicted for a half sine wave pulse. This difference is due to the drop-table pulses having less "area under the curve" than a similar duration half sine pulse. Figure 5-8 shows a comparison of a drop-table pulse to a half sine wave pulse of the same duration and peak magnitude.

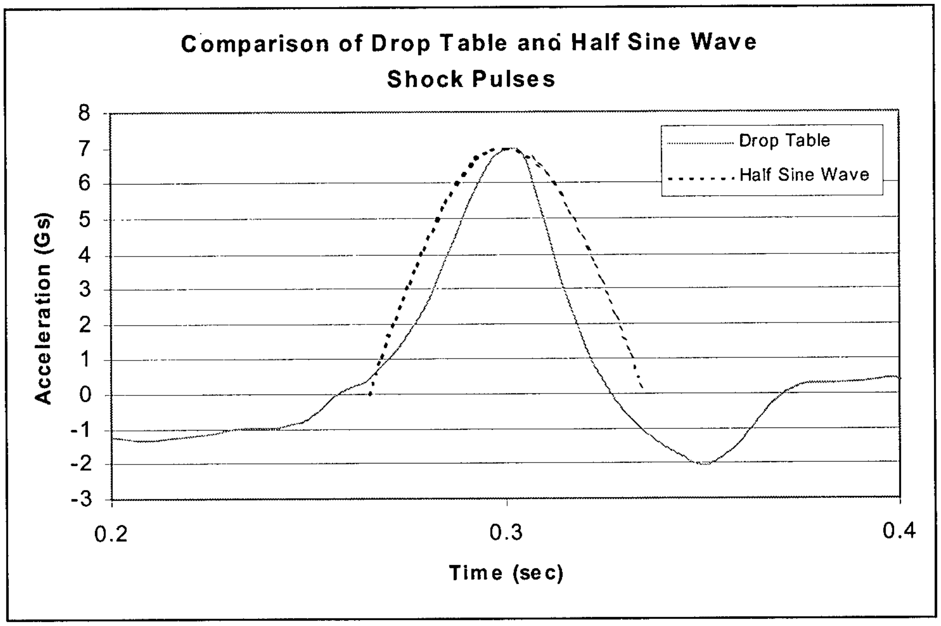


FIGURE 5-8: COMPARISON OF DROP TABLE AND HALF SINE WAVE PULSE SHAPES

As the figure shows, the half sine wave pulse has more area under the curve, so the change due to the half sine wave acceleration history is greater than that of the drop-table pulse. The result is that for a given impact velocity, the peak acceleration predicted for a half sine wave pulse is slightly less than the actual peak obtained from the drop table. In practice, the drop table generated pulses are very close approximations of the initial impact shock events seen on the boats (Haupt, 1996,1997 and Peterson, 1997) and in any event are closer approximations than a simple half sine wave.

The drop table was also able to produce excellent repeatability, which can be seen in Figure 5-9.

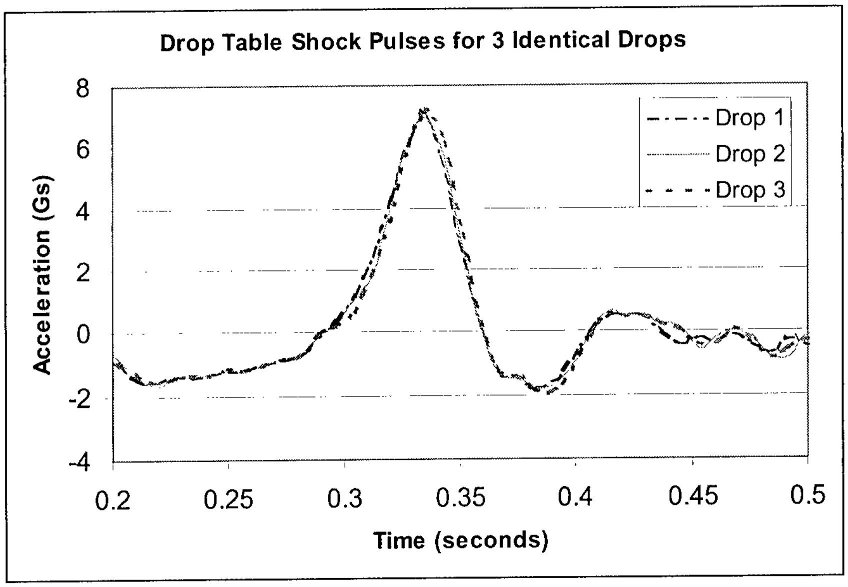


FIGURE 5-9: EXAMPLE OF REPEATABILITY OF DROP TABLE SHOCK PULSES

This repeatability was also seen in the response curves for the STIDD model 800v5 seat testing, which will be discussed later in this section.

Thorough exploration of the range of capabilities and applications for the drop table system was not possible due to time constraints related to this particular project. However, the goal of creating and validating a laboratory test apparatus was accomplished, and this system will further developed and applied to the shock mitigation problem as part of continuing masters degree research in this area by other students.

5.4 Testing and Evaluation of the STIDD Model 800v5 Seat

Drop Table Dynamics

This section details the use of the drop-table system in the test and evaluation of a commercially available shock-mitigating seat. Before beginning this discussion, it is a good opportunity to examine the dynamics of the drop-table (with test system mounted), specifically during free-fall from the moment the drop table is released to the moment of impact. Consider a generic passive isolation system consisting of a linear spring (with spring constant (k) in units of force/distance) and a viscous damping element (with damping coefficient (B) in units of force/velocity). First we look at the system before and after the application of the static load (e.g.- the seat occupant). Figure 5-10 shows the static system in both its unloaded and loaded states.

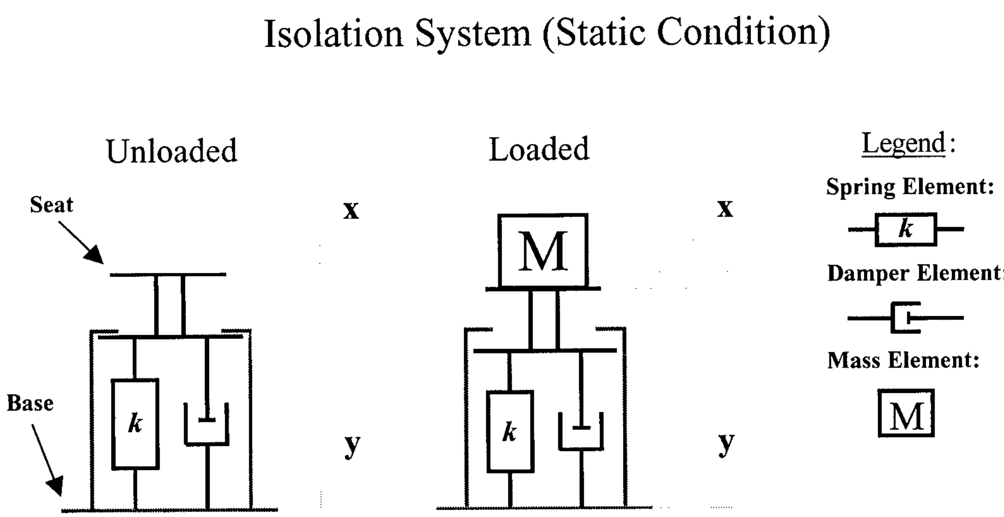


FIGURE 5-10: SCHEMATIC DIAGRAMS OF THE STATIC SEAT (LOADED AND UNLOADED)

The figure shows schematics of loaded and unloaded system as well as a coordinate system, which will be used in analyzing system motion. The system has a finite range of motion, which results from the design limitations of the spring and damper. To protect these components from damage due to excessive travel, suspension systems typically employ mechanical stops at the top and bottom. As seen in the unloaded case, the system is hard up against its top motion stop so that maximum displacement is available for compressive loading (both static and dynamic). When the static load is applied to the system, the spring and damper are compressed downward until the spring force is equal to the load force (i.e- until $kx = mg$). So, in the loaded state, the system has already undergone a negative vertical displacement and is no longer hard against its top stop. This is the condition the suspension system would typically be in just prior to being dropped on the drop-table test machine. To the motion of this total system, it can be broken down into two sections, the seat (supported by the suspension) and the base (mounted to and supported by the drop table). Figure 5-11 shows free body diagrams (FBD) of the system, just before ($t=0^-$) and just after ($t=0^+$) drop table release. Since there is no motion in the system in the time prior to release and the instant following release (and therefore no velocity), the damper can be ignored.

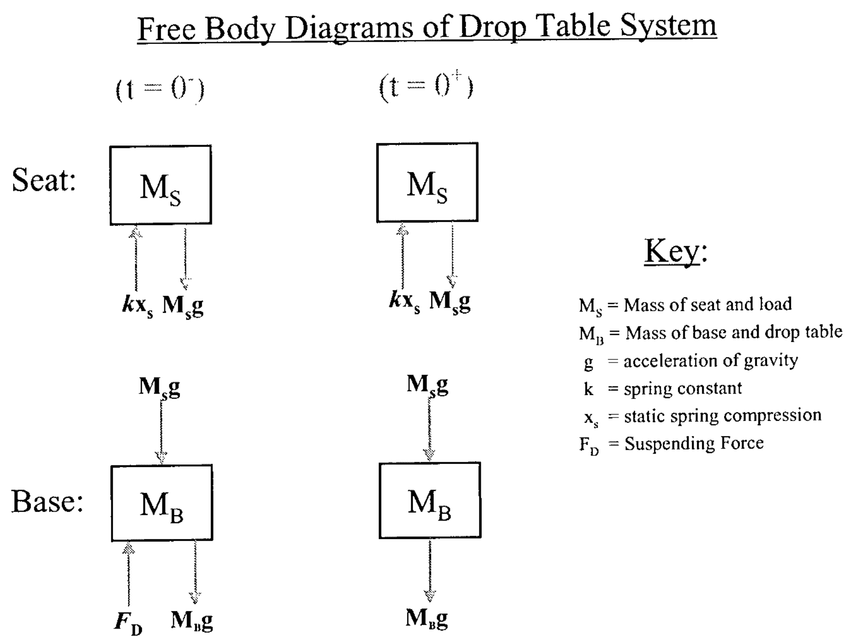


FIGURE 5-11: FREE BODY DIAGRAMS OF SEAT AND BASE AT MOMENT OF DROP TABLE RELEASE

Prior to the release of the table there is no system motion so the equations of motion are trivial. However, in the instant following the drop table release ($t=0^+$), the equations of motion for the FBDs become:

$$\text{Seat:} \quad M_s \bullet \ddot{x} - M_s \bullet g + k \bullet x_s = 0$$

$$\text{Base:} \quad M_B \bullet \ddot{y} - M_B \bullet g - k \bullet x_s = 0 \tag{5.3}$$

Since at the moment of drop table release there has been no motion yet, the spring force term (kx_S) is equal in magnitude to the static weight of the seat (M_Sg). Solving these equations for acceleration yields:

$$\ddot{x}_{0^+} = 0, \qquad \ddot{y}_{0^+} = g\left(1 + \frac{M_s}{M_B}\right) \tag{5.4}$$

So, we find the interesting result that at the moment the drop table is released, the seat has no acceleration and the base has acceleration greater than that due to gravity. For the drop table used in this project, the base and seat (loaded) had roughly the same mass. This means that the base section should have an initial acceleration of approximately 2 Gs. Figure 5-12 is a plot of free-fall accelerations for a drop on our table.

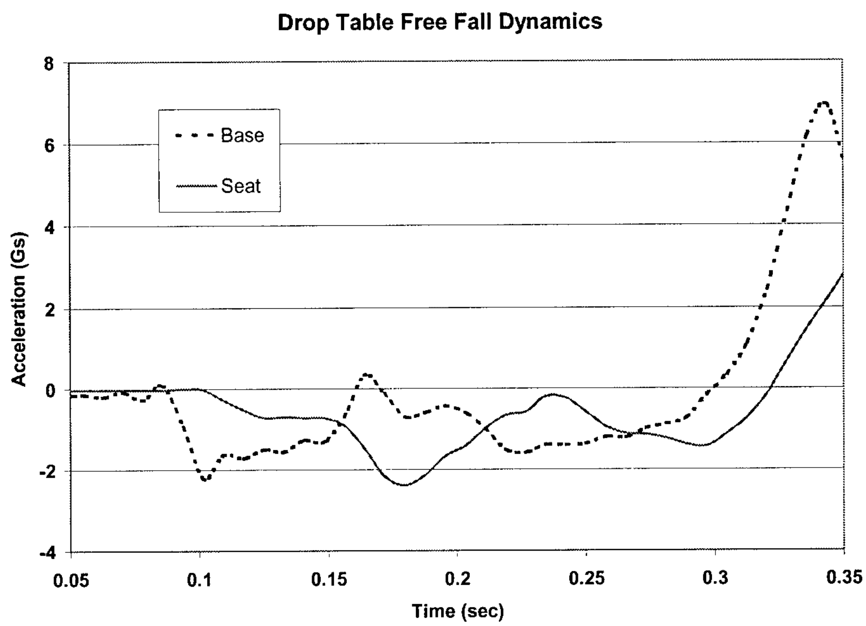


FIGURE 5-12: FREE BODY DIAGRAMS OF SEAT AND BASE AT MOMENT OF DROP TABLE RELEASE

As the figure shows, the actual drop table dynamics have excellent agreement with our calculations. The base quickly reaches an acceleration of about 2 Gs while the seat is still motionless. As the base reaches its maximum negative acceleration we see that the seat now begins to accelerate as well. Newton's laws stipulate that the center of gravity of the system must have a net acceleration in free-fall equal to the acceleration of gravity. So, while the seat and base have different instantaneous accelerations during free-fall, the net acceleration of the drop-table is one gravity. The seat and base then behave as a two mass system connected by a spring. An analysis of the mode shapes of this system (undamped case) reveals two modes. The first mode has zero natural frequency (i.e. - the seat and base move as a single rigid system) and the second mode frequency is given by:

$$\omega_n = \sqrt{\frac{k(M_S + M_B)}{M_S \bullet M_B}} \tag{5.5}$$

This indicates a frequency in free-fall of 1 to 1.414 times the natural frequency of the single-degree-of-freedom (sdof) seat suspension system alone (i.e. $\sqrt{\frac{k}{M_s}}$). The maximum frequency occurs when the seat and base have equal mass. As the base mass approaches infinity, the frequency approaches ($\sqrt{\frac{k}{M_s}}$). While not calculated in our brief examination here, the effect of the damper can be seen in Figure 5-12 in which the amplitudes of oscillation during free-fall diminish with each cycle.

The important point of this free-fall analysis is what affect it has on the seat response and how the drop-table dynamics differ from those seen on the boats. On the boat the base mass is orders of magnitude greater than the seat mass, so the free-fall frequency would be closely predicted by ($\sqrt{\frac{k}{M_s}}$). For our drop-table apparatus, the seat and base masses are roughly the same, which (from equation 5.5) results in free-fall oscillations that are about 1.4 times the frequency of the sdof seat suspension case. Does this difference change the way the seat performs on the boats as compared to the drop-table? While free-fall response may be slightly different for a specific time during free-fall, this should have little affect on how the overall seat response following impact.

The most significant factors affecting the drop are the velocity at the moment of impact, and the relative position of the seat with respect to the base at impact. Since the velocity at impact can be easily adjusted on the drop-table system by varying drop height (and is a function of seas, speed etc. on the boat) it is not seen as an important factor. However, the displacement of the seat (relative to the base) at the moment of impact (due to this free-fall oscillation) could potentially affect the seat response following impact. As Figure 5-12 shows, the amplitude of the oscillations are fairly small by the time impact occurs, so there would be little expected affect on seat response. Any such effects could be reduced or eliminated by increasing the damping, or imposing static preload on the spring (so that the seat does not leave its top stop when statically loaded by the occupant). Both of these methods change the way the system behaves as well, so there is an obvious trade-off. In general, these free-fall dynamics are seen as having little significant impact on the overall system response and no specific effort was made to eliminate them.

Seat Testing

Having established the ability of the drop-table apparatus to generate shock pulses like those seen on special warfare boats, the effectiveness of the drop-table in testing an actual shock isolation system was evaluated. A STIDD Model 800v5 seat was obtained from STIDD Systems Inc. for this test and evaluation phase, and the seat can be seen mounted on the drop-table in Figure 5-3. The STIDD 800v5, a modified version of the stationary 800v4 seat, incorporates a spring-damper element between the seat foundation and the seat itself. In order to allow for suspension operation, the v5 seat has fixed vertical height (the v4 allows for the seat to be raised and lowered) and the seat pan cannot be lowered (i.e.- cannot be used as a standing bolster). The production model uses a 5 volt DC power supply to power an adjustable damping system, which allows the occupant to "dial-in" any desired damping within the maximum and minimum settings. In order to allow repeatable testing at specific damper settings, the test seat used had a manually adjustable damping via a knob with nine discrete set points. For our testing, 3 damper settings were used. These settings (which hereafter will be referred to as Minimum, Medium and Maximum) correspond to positions 1, 4 and 9 on the damper adjustment knob respectively. For safety reasons, lumped mass (in the form of steel plates) was used in place of an actual human occupant for the majority of the testing, although a small number of lower magnitude test drops were performed with a human subject to assess the affect of the human body dynamics on seat operation.

Since the focus of this exercise was to validate the capability of the drop-table to test and evaluate a shock isolation system (as opposed to thoroughly testing and evaluating the shock isolation system itself), a complete matrix of test parameters was not used. The overall performance of the STIDD seat was analyzed however, based on three forms of test results: 1) The percent reduction in shock magnitude, 2) Comparison of DRI numbers between the unsuspended seat foundation and the suspended seat pan, and 3) Transmissibility curves for the suspended seat. As discussed previously, the percent reduction in shock magnitude is not necessarily a definite indicator of performance by itself. However, this data does provide information on the system's ability to filter shock energy for a given shock event and so it is included here.

Test drops were made with lumped mass weights varying from 180lbs to 205lbs (not including the mass of the seat itself). The results shown below are for test drops using 195lbs of lumped mass. However, the overall pattern of performance for the seat was similar for all lumped masses used. STIDD 800 seats have similar seat cushions and bolsters, and our test seat differed mainly by the addition of the suspension element. In order to isolate this suspension system for evaluation, the seat cushion was removed for a portion of the testing. In other testing, the cushion's effects were minimized by applying a large pre-load (via ratchet tie downs on the lumped mass). Drops were made from 6, 7, 12 and 18-inch drop heights, and excellent repeatability for both the base excitation and seat pan shock pulses was obtained as Figure 5-13 shows.

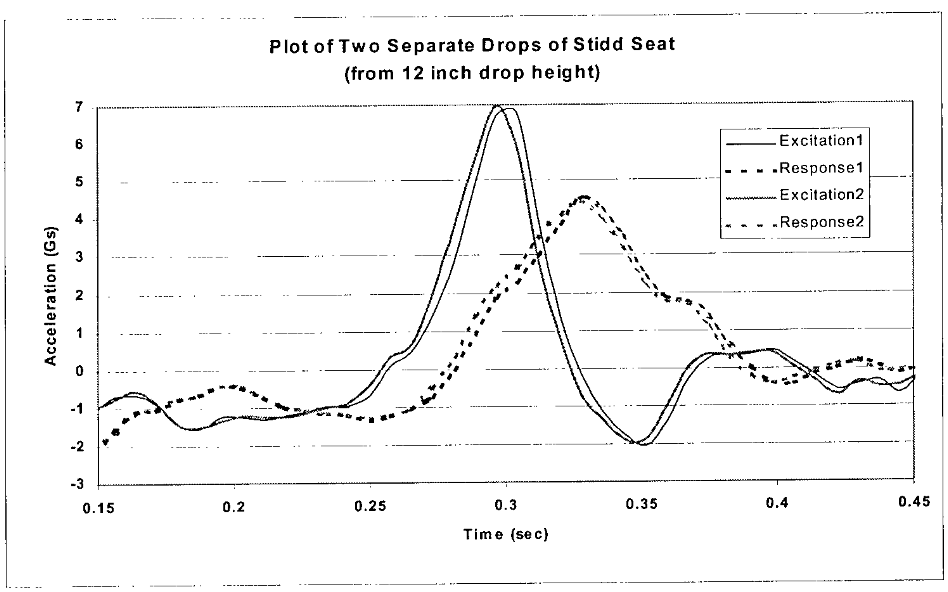


FIGURE 5-13: EXAMPLE OF STIDD SEAT RESPONSE AND REPEATABILITY

The reduction in shock magnitude between the base and the seat is clearly visible in this figure. Another notable feature is that the shock pulse duration seen at the seat pan is significantly longer than that of the incoming excitation pulse. This amounts to the seat effectively filtering out a significant portion of the shock pulse energy by operating at a more favorable natural frequency and damping ratio.

By measuring the base acceleration as well as the accelerations at the seat pan, the performance of the suspension seat can be compared to that of a rigid seat. Using the single-degree-of-freedom DRI model discussed earlier, a DRI number was calculated for the base excitation, and seat pan response, for a number of different drops with various drop heights and damper settings. Figure 5-14 shows a summary of the DRI results from the testing.

Damper Setting:	Location:	Drop Height:			
		6 inch	**7 inch**	**12 inch**	**18 inch**
Min	Base	5.1	5.6	7.2	
	Seat	4.8	3.8	5.9	
Med	Base	6	6.7	7.2	11.2
	Seat	3.9	3.9	5.9	7.8
Max	Base	6.3	6.3	7.2	
	Seat	4.1	4.9	5.9	

FIGURE 5-14: SUMMARY OF DRI RESULTS FOR STIDD SEAT TESTS

As the data in Figure 5-11 show, the seat suspension provides a definite reduction in the DRI number at all damper settings and for all drop heights tested. The Medium damper setting demonstrated the best performance in reducing DRI. Comparing these DRI numbers to the DRI injury risk chart (Figure 3-9) it can be seen that low to moderate impacts (in the 3-6 G range for instance) the seat performs well at mitigating the shock to a level below the injury threshold. For the higher magnitude shocks, however, even the mitigated shocks result in DRI values of 5.9 or more. A DRI value of roughly 5 or more can potentially be injury causing if enough impacts of this magnitude are received (It is quite common for the boat crews and passengers to experience several hundred significant impact shocks on single mission). Several hundred impacts with a DRI of 5.9

or more would put the unlucky recipient into the injury risk zone. Even for the cases in which DRI is reduced below the injury threshold, it is still located in a region of moderate to severe discomfort. While this discomfort may not directly cause injury, it can result in fatigue and lack of concentration in the crew, which can raise the risk of injury.

The final performance criterion tested was the seat transmissibility. Using SigLab® in its network analysis mode, the seat was dropped 5-10 times at a set height and damper position. The SigLab® software automatically performs the necessary signal processing on the base excitation and seat response signals to generate a transfer function. By averaging the transfer function over several drops, a representative transfer function with good coherence is obtained. Figure 5-15 shows these transmissibility curves for three different damper settings.

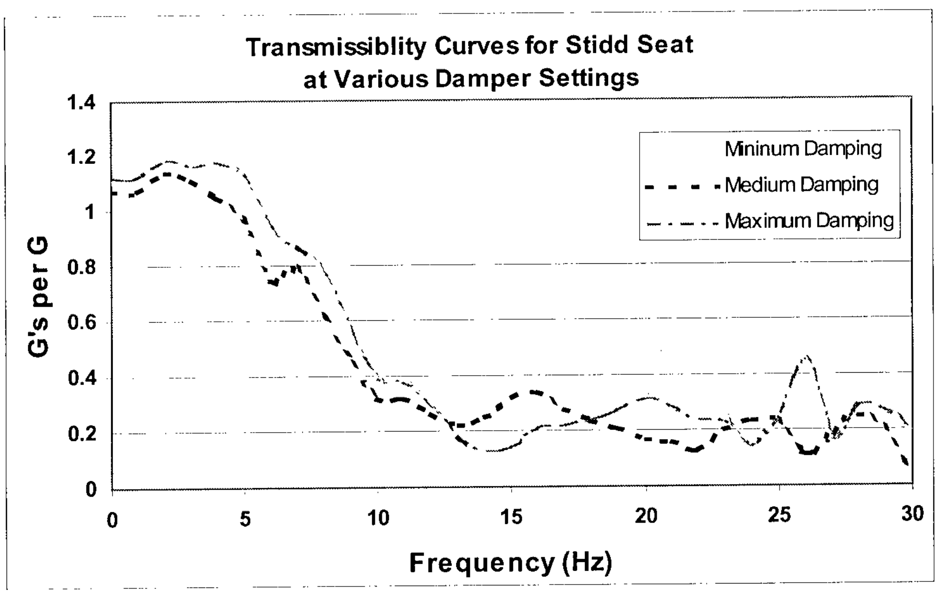


FIGURE 5-15: STIDD SEAT TRANSMISSIBILITY CURVES

Note that the curves are very similar to those of the suspension seats mentioned in Chapter 4 (Figure 4-12). As seen with the DRI data, these curves indicate that the seat performs best at its Medium damper setting, with performance at the Maximum damper setting next. The effect of the seat striking its top stop (when under minimum damping) can be seen here by the spike on the Minimum damping curve at approximately 22 Hz.

Note that for excitations of 5Hz or greater, the seat can provide transmissibility of 1.0 or less (i.e.- some degree of reduction) and for excitations of 8-10Hz and greater, the drop in transmissibility is significant. Since the majority of the shock events seen on the boats are 30-50 milliseconds in duration (for the initial impact pulse), this seat could be expected to perform reasonably well at mitigating these impacts. However, larger magnitude impacts (especially those which cause the seat to bottom out) are not adequately mitigated by the seat. Some potential design changes to address these issues will be discussed in Chapter 6.

Chapter 6

6.0 Conclusions and Recommendations

6.1 Problem Existence

Anecdotal evidence, backed up by injury compilation reports, craft motion studies, and injury prediction models, clearly show a connection between service aboard high-speed boats and an increased rate of acute and chronic injury. The mechanical shock environment seen on these boats during typical operations can range from mild to extremely severe depending on sea-state and other factors. The existing shock mitigation systems and doctrine (or lack of) currently in use on these boats are insufficient to adequately protect the crew and passengers from injury. Action is needed at every avenue, from training and conditioning of personnel to design and implementation of effective shock isolation systems, in order to properly address this problem.

6.2 Injury Prediction and Modeling

The existing injury models (e.g.- DRI and Glaister) are limited in their application and fall well short of providing engineers and boat builders the necessary information to design and build effective and integrated shock mitigating boat hulls and suspension systems. Likewise, this lack of knowledge on injury mechanisms due to shock exposure makes it difficult to properly track and manage personnel exposure to mechanical shock in order to prevent injury from cumulative effects. The reason for this is that until we know where we need to get to (in terms of shock magnitude limits, exposure limits, etc.), we cannot design and develop engineering solutions with the appropriate amount of rigor. The current design point in use is simply that, "less shock magnitude is better." While this may serve well in a philosophical discussion, it is not nearly specific enough for use in engineering applications. Efforts such as the one recently begun at the University of Virginia, in cooperation with NCSS, USSOCOM and others, will hopefully provide the information needed to develop accurate and comprehensive injury prediction models for the range of applications seen in the special boat unit community. Adequate support and funding of these studies is crucial and should take priority over other efforts related to this problem.

6.3 Methods of Shock Mitigation

Our previous discussion, on the areas in which shock mitigation is possible, primarily touched on the more recent or promising developments in this area. The most likely approach to the problem would be to divide it into near and far-term goals. In the near term, the so-called "low hanging fruit" can be exploited more quickly to provide at least some measure of added protection to the fleet while new boat and system designs are being developed and tested. Implementing intrusive design changes such as H-STEP, ODH, and suspended decks, into the existing special warfare craft would be prohibitive in both cost and time. Therefore, near-term fixes must be "bolt-on" in nature, such as improved seating, bolsters and restraints, deck cushioning, and ergonomic modifications. As stated previously, efforts involving personnel training and conditioning, as well as changes in the doctrine of how the boats are operated (e.g.- max speeds in certain sea states, etc.) can be implemented immediately.

One near term option that is being discussed is to replace the boat crew seats on the MkV SOC with some sort of suspension seat design. The footprint of the existing STIDD seats would allow any number of existing seating systems to fit with little or no change in arrangement. Likely candidates would be the Ullman "Jockey Seat" or the STIDD 800v5 seat. The Ullman seat, as demonstrated in testing by NCSS, provides definite reduction in vertical shock and also places the occupant in a good posture for sustaining lateral impacts. However, this seat would require modifications to the MkV, in both seat arrangement and boat controls, in order to be installed. The STIDD v5 seat offers the advantage of having essentially identical footprint and mounting hardware, as well as the same pilot and navigator control system. However, as discussed in Chapter 5, this seat currently provides adequate protection for low to medium level impacts only, with no ability to convert from a sitting to a standing posture.

There are certain design changes, which could likely be made to the STIDD 800v5 seat to make it more suitable to the full range of MkV SOC employment. The recommended changes are: (1) Raising of the base seat height, and incorporation of a hinged seat pan (like that on the existing v4 seat), to allow use in both sitting and standing postures, (2) Incorporation of suspension system in both sitting and standing postures (rather than just sitting), (3) Removal of the forearm rests (but retaining the handgrips) to minimize impact loading to the shoulder complex, (4) Incorporation of throttle controls on the pilot and navigator seats to allow complete speed and directional control while seated or standing, (5) Possible modification of the suspension element to add extra travel length (and perhaps lower the spring stiffness), which would allow a better range of shock isolation performance.

While no detailed discussion of potential far-term solutions will be made, there are a number of design related issues, which should be considered for next generation special warfare boats. Previous and existing boat designs, while highly capable in areas such as speed and maneuverability, appear to have lacked comprehensive design requirements and effective system integration. Some examples of poor ergonomic design and non-optimal arrangement of personnel and equipment are: 1) Placing the electronics suite on the MkV in the forward section of the boat where the most severe impact shocks are felt, 2) Installing control consoles such as navigation, radar, throttles, and propulsion such that they cannot be reached or operated while seated, and 3) Use of a propulsion system that can sustain speeds in excess of mission needs and far in excess of what the human occupants can safely withstand in rough seas.

These comments are not intended as condemnation of the boat designers, rather they are meant to illuminate an important fact... the boats needed for use by the special warfare community pose a complex design problem and do not have commercial-off-the-shelf (COTS) equivalents. Commercial small boat builders, unlike the huge shipyards that build major combatant vessels, lack the personnel, resources, and capital to perform optimal, requirements driven, integrated boat design for special warfare craft. In order to profit from such an undertaking, a boat builder would need to sell hundreds (or more likely thousands) of such boats, which is far more than would be purchased by any DOD contract. Because of the prohibitive cost of a comprehensive integrated boat design, attempts are made by commercial boat builders to simply modify COTS boat designs for use by special warfare, with the results being boats that break people, equipment, and themselves.

Despite noted resistance to the idea by some within the Navy and DOD small boat design community, the best way to address this problem would be for the DOD to commission, oversee, and fund the design and development of special warfare craft and then allow commercial boat builders to bid on the actual construction of the final DOD provided designs. In this way, a systems integration approach (e.g.- Total Ship Systems Design and Engineering methods) could be properly applied in order to arrive at an optimal balanced design without subjecting any single boat builder to the prohibitive cost of such an undertaking. The cost of such a rigorous and specialized design effort may indeed be cost prohibitive for a commercial boat builder who will likely end up selling only a few dozen copies. However, the potential savings for the special warfare community in terms of personnel injury and disability, damaged equipment, and reduced mission effectiveness, far exceed the cost of such a design effort.

6.4 Testing and Evaluation

As discussed in Chapter 5, the basic methods of testing and evaluating shock mitigation systems are At-sea testing and Laboratory testing. There are distinct advantages and disadvantages to both of these methods (and the best approach is most likely a combination of the two).

At-sea testing allows the system to be evaluated under real-world conditions, incorporating all of the inherent non-linearity and randomness of the mechanical shock environment seen on the boats at sea. However, due to the random and non-linear nature of the at-sea environment, it is virtually impossible to obtain any repeatability in conditions between tests. This lack of repeatability makes it difficult to compare the system performance between one test and another. Likewise, it is impossible to generate a specific shock environment when testing at sea. While certain methods, such as wake jumping and varying course and speed relative to the seas, can generate a wide range of shock environments, they cannot produce a specific shock event (magnitude, duration and shape) nor can they reliably reproduce a given shock event over and over again. At-sea testing can also be quite expensive, manpower intensive, and highly dependent on weather conditions.

The shock environments produced in laboratory testing typically lack the randomness and non-linear character of the actual at-sea environment, but they are able to provide excellent dial-in (i.e.- selection of specific shock characteristics) and repeatability. By providing the ability to subject one or more shock isolation systems to identical shock events as often as necessary, laboratory testing allows a much more controlled approach and fine-tuning of design performance. Once the initial capital investment has been made in purchasing or constructing laboratory test equipment, the difficulty and cost of conducting laboratory tests are relatively minor. A good combination of laboratory and at-sea testing would likely involve preliminary design and development using lower cost and more available laboratory testing, followed by more costly at-sea trials of the final design.

This study has validated the use of a laboratory drop-table test device for the design and evaluation of shock isolation systems. This system provides the design or test engineer the ability to subject a shock isolation system to a wide range of shock events, with a high degree of repeatability and dial-in capability. Laboratory based testing is typically much cheaper and less manpower intensive than at-sea testing, and is a logical starting point in design development, with at-sea tests conducted only after a design has performed satisfactorily in the lab. While the full range of capabilities of the drop-table system have not yet been explored, its application to this problem has been established and continuing development and use of this test system is planned.

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Appendix A

(At-Sea Shock Recorder Data)

MkV SOC Shock Data

(data taken during routine training op using IST Snapshock data recorder)

	Shock Magnitude (Gs)			Shock Duration (sec)		
Date/Time of Shock Event:	Long (x-axis)	Vertical (z-axis)	Lateral (y-axis)	Long (x-axis)	Vertical (z-axis)	Lateral (y-axis)
08/09/2000 20:03	0	1.657	0	0	0.013	0
08/09/2000 20:03	0	1.736	0	0	0.013	0
08/09/2000 20:03	0	1.736	0	0	0.016	0
08/09/2000 20:03	0	2.131	0	0	0.013	0
08/09/2000 20:03	0	1.894	0	0	0.018	0
08/09/2000 20:03	0	1.894	0	0	0.013	0
08/09/2000 20:04	0	1.894	0	0	0.025	0
08/09/2000 20:04	0	2.21	0	0	0.015	0
08/09/2000 20:04	0	1.579	0	0	0.013	0
08/09/2000 20:04	0	1.579	0	0	0.013	0
08/09/2000 20:04	0	2.289	0	0	0.023	0
08/09/2000 20:04	0	2.289	0	0	0.013	0
08/09/2000 20:04	0	1.657	0	0	0.013	0
08/09/2000 20:04	0	-1.657	2.133	0	0.007	0.012
08/09/2000 20:04	0	1.973	0	0	0.017	0
08/09/2000 20:04	0	1.657	0	0	0.013	0
08/09/2000 20:04	0	1.657	0	0	0.013	0
08/09/2000 20:04	0	1.579	0	0	0.013	0
08/09/2000 20:04	0	3.157	0	0	0.061	0
08/09/2000 20:04	0	2.92	0	0	0.023	0
08/09/2000 20:04	0	1.579	0	0	0.013	0
08/09/2000 20:04	0	1.736	0	0	0.013	0
08/09/2000 20:04	0	1.736	0	0	0.014	0
08/09/2000 20:04	0	1.815	0	0	0.013	0
08/09/2000 20:04	0	2.605	0	0	0.013	0
08/09/2000 20:05	0	1.579	0	0	0.013	0
08/09/2000 20:05	0	3.236	-1.896	0	0.04	0.013
08/09/2000 20:05	0	2.289	0	0	0.019	0
08/09/2000 20:05	0	1.579	0	0	0.013	0
08/09/2000 20:05	0	1.736	0	0	0.023	0
08/09/2000 20:05	0	1.657	0	0	0.013	0
08/09/2000 20:05	0	1.579	0	0	0.013	0
08/09/2000 20:05	0	1.579	0	0	0.013	0
08/09/2000 20:05	0	1.579	0	0	0.013	0
08/09/2000 20:05	0	1.579	0	0	0.013	0
08/09/2000 20:05	0	1.736	0	0	0.013	0
08/09/2000 20:05	0	4.025	0	0	0.105	0
08/09/2000 20:05	0	1.657	0	0	0.013	0
08/09/2000 20:05	0	1.815	0	0	0.013	0
08/09/2000 20:07	0	2.762	0	0	0.098	0
08/09/2000 20:07	0	2.289	0	0	0.043	0
08/09/2000 20:07	0	1.579	0	0	0.013	0
08/09/2000 20:07	0	1.736	0	0	0.013	0
08/09/2000 20:07	0	1.815	0	0	0.023	0
08/09/2000 20:07	0	1.815	0	0	0.013	0
08/09/2000 20:07	0	1.736	0	0	0.013	0
08/09/2000 20:08	0	2.052	0	0	0.013	0
08/09/2000 20:08	0	1.579	0	0	0.013	0
08/09/2000 20:08	0	2.21	0	0	0.02	0
08/09/2000 20:08	0	1.579	0	0	0.013	0
08/09/2000 20:08	0	4.578	0	0	0.089	0

08/09/2000 20:08	0	3.236	0	0	0.038	0
08/09/2000 20:08	0	2.21	0	0	0.013	0
08/09/2000 20:08	0	1.657	0	0	0.013	0
08/09/2000 20:08	0	1.579	0	0	0.013	0
08/09/2000 20:08	0	1.579	0	0	0.013	0
08/09/2000 20:08	0	2.368	0	0	0.013	0
08/09/2000 20:08	0	1.657	0	0	0.013	0
08/09/2000 20:08	0	2.447	0	0	0.016	0
08/09/2000 20:08	0	1.973	0	0	0.02	0
08/09/2000 20:08	0	1.736	0	0	0.013	0
08/09/2000 20:08	0	1.894	0	0	0.013	0
08/09/2000 20:08	0	1.973	0	0	0.016	0
08/09/2000 20:08	0	2.684	0	0	0.029	0
08/09/2000 20:08	0	0	2.449	0	0	0.013
08/09/2000 20:08	0	2.999	0	0	0.115	0
08/09/2000 20:08	0	2.21	0	0	0.049	0
08/09/2000 20:08	0	1.973	0	0	0.021	0
08/09/2000 20:08	0	2.762	0	0	0.009	0
08/09/2000 20:08	0	1.657	0	0	0.013	0
08/09/2000 20:08	0	1.579	0	0	0.013	0
08/09/2000 20:08	0	2.289	0	0	0.013	0
08/09/2000 20:08	0	1.894	0	0	0.018	0
08/09/2000 20:08	0	1.973	0	0	0.013	0
08/09/2000 20:08	0	3.157	0	0	0.111	0
08/09/2000 20:08	0	2.131	0	0	0.052	0
08/09/2000 20:08	0	1.736	0	0	0.013	0
08/09/2000 20:08	0	2.368	0	0	0.013	0
08/09/2000 20:08	0	1.736	0	0	0.013	0
08/09/2000 20:08	0	3.315	0	0	0.098	0
08/09/2000 20:08	0	2.684	0	0	0.025	0
08/09/2000 20:09	0	1.579	0	0	0.013	0
08/09/2000 20:09	0	1.657	0	0	0.013	0
08/09/2000 20:09	0	1.894	0	0	0.013	0
08/09/2000 20:09	0	1.579	0	0	0.013	0
08/09/2000 20:27	0	1.736	0	0	0.014	0
08/09/2000 20:27	0	1.579	0	0	0.013	0
08/09/2000 20:27	0	1.894	0	0	0.013	0
08/09/2000 20:27	0	1.657	0	0	0.013	0
08/09/2000 20:27	0	1.736	0	0	0.013	0
08/09/2000 20:27	0	3.473	0	0	0.186	0
08/09/2000 20:27	0	1.973	0	0	0.019	0
08/09/2000 20:27	0	1.815	0	0	0.013	0
08/09/2000 20:27	0	3.157	0	0	0.108	0
08/09/2000 20:27	0	1.973	0	0	0.016	0
08/09/2000 20:27	0	1.736	0	0	0.013	0
08/09/2000 20:27	0	1.579	0	0	0.013	0
08/09/2000 20:27	0	2.052	0	0	0.05	0
08/09/2000 20:27	0	3.236	0	0	0.132	0
08/09/2000 20:27	0	2.21	0	0	0.022	0
08/09/2000 20:27	0	2.052	0	0	0.126	0
08/09/2000 20:27	0	2.684	0	0	0.12	0
08/09/2000 20:27	0	1.894	0	0	0.013	0
08/09/2000 20:27	0	2.447	0	0	0.015	0
08/09/2000 20:27	0	3.71	0	0	0.044	0
08/09/2000 20:27	0	2.052	0	0	0.043	0
08/09/2000 20:27	0	1.657	0	0	0.013	0
08/09/2000 20:27	0	1.579	0	0	0.013	0
08/09/2000 20:27	0	1.973	0	0	0.014	0
08/09/2000 20:27	0	1.579	0	0	0.013	0
08/09/2000 20:27	0	2.447	0	0	0.102	0
08/09/2000 20:27	0	1.736	0	0	0.014	0
08/09/2000 20:27	0	2.92	0	0	0.162	0
08/09/2000 20:27	0	1.579	0	0	0.013	0
08/09/2000 20:27	0	2.052	0	0	0.017	0

08/09/2000 20:27	0	4.262	0	0	0.114	0
08/09/2000 20:27	0	2.999	0	0	0.071	0
08/09/2000 20:27	0	1.973	0	0	0.038	0
08/09/2000 20:28	0	4.972	0	0	0.22	0
08/09/2000 20:28	0	2.052	0	0	0.027	0
08/09/2000 20:28	0	1.579	0	0	0.013	0
08/09/2000 20:28	0	3.236	0	0	0.112	0
08/09/2000 20:28	0	2.526	0	0	0.013	0
08/09/2000 20:28	0	1.736	0	0	0.023	0
08/09/2000 20:28	0	1.736	0	0	0.014	0
08/09/2000 20:28	0	2.92	0	0	0.103	0
08/09/2000 20:28	0	2.447	0	0	0.017	0
08/09/2000 20:28	0	2.131	0	0	0.067	0
08/09/2000 20:28	0	2.447	0	0	0.023	0
08/09/2000 20:37	0	3.078	0	0	0.127	0
08/09/2000 20:37	0	2.21	0	0	0.03	0
08/09/2000 20:37	0	1.657	0	0	0.013	0
08/09/2000 20:37	0	1.579	0	0	0.013	0
08/09/2000 20:37	0	3.157	0	0	0.148	0
08/09/2000 20:37	0	1.894	0	0	0.016	0
08/09/2000 20:37	0	1.657	0	0	0.013	0
08/09/2000 20:37	0	1.736	0	0	0.014	0
08/09/2000 20:37	0	1.579	0	0	0.017	0
08/09/2000 20:38	0	1.894	0	0	0.013	0
08/09/2000 20:38	0	1.579	0	0	0.013	0
08/09/2000 20:38	0	2.684	0	0	0.108	0
08/09/2000 20:38	0	1.815	0	0	0.02	0
08/09/2000 20:38	0	1.736	0	0	0.013	0
08/09/2000 20:38	0	2.131	0	0	0.015	0
08/09/2000 20:38	0	2.841	0	0	0.088	0
08/09/2000 20:38	0	2.526	0	0	0.034	0
08/09/2000 20:38	0	3.867	0	0	0.133	0
08/09/2000 20:38	1.651	2.21	0	0.013	0.013	0
08/09/2000 20:38	0	1.657	0	0	0.014	0
08/09/2000 20:38	0	1.579	0	0	0.013	0
08/09/2000 20:38	0	1.657	0	0	0.013	0
08/09/2000 20:38	0	2.762	0	0	0.082	0
08/09/2000 20:38	0	1.973	0	0	0.013	0
08/09/2000 20:38	0	1.579	0	0	0.013	0
08/09/2000 20:38	0	1.579	0	0	0.013	0
08/09/2000 20:38	0	2.762	0	0	0.154	0
08/09/2000 20:38	0	1.894	0	0	0.017	0
08/09/2000 20:38	0	4.025	0	0	0.124	0
08/09/2000 20:38	0	2.368	0	0	0.036	0
08/09/2000 20:38	0	1.657	0	0	0.013	0
08/09/2000 20:38	0	2.841	0	0	0.119	0
08/09/2000 20:38	0	2.762	0	0	0.029	0
08/09/2000 20:38	0	1.815	0	0	0.013	0
08/09/2000 20:38	0	3.631	-1.58	0	0.142	0.012
08/09/2000 20:38	0	1.815	0	0	0.013	0
08/09/2000 20:38	0	2.052	0	0	0.039	0
08/09/2000 20:38	0	1.657	0	0	0.013	0
08/09/2000 20:38	0	1.579	0	0	0.013	0
08/09/2000 20:38	0	2.21	0	0	0.067	0
08/09/2000 20:38	0	2.92	0	0	0.033	0
08/09/2000 20:38	0	2.762	0	0	0.046	0
08/09/2000 20:38	0	2.684	0	0	0.132	0
08/09/2000 20:38	0	1.736	0	0	0.027	0
08/09/2000 20:38	0	4.104	0	0	0.211	0
08/09/2000 20:38	0	2.92	0	0	0.157	0
08/09/2000 20:38	0	2.052	0	0	0.036	0
08/09/2000 20:38	0	1.579	0	0	0.013	0
08/09/2000 20:38	0	3.078	0	0	0.02	0
08/09/2000 20:38	0	2.447	0	0	0.031	0

08/09/2000 20:38	0	1.579	0	0	0.013	0
08/09/2000 20:38	0	1.579	0	0	0.013	0
08/09/2000 20:38	0	2.762	0	0	0.111	0
08/09/2000 20:38	0	2.131	0	0	0.013	0
08/09/2000 20:38	0	1.579	0	0	0.013	0
08/09/2000 20:38	0	1.657	0	0	0.015	0
08/09/2000 20:38	0	2.526	0	0	0.042	0
08/09/2000 20:38	0	1.815	0	0	0.013	0
08/09/2000 20:38	0	1.579	0	0	0.013	0
08/09/2000 20:38	0	2.368	0	0	0.147	0
08/09/2000 20:38	0	1.894	0	0	0.019	0
08/09/2000 20:38	0	1.657	0	0	0.013	0
08/09/2000 20:39	0	2.21	0	0	0.013	0
08/09/2000 20:39	0	1.657	0	0	0.015	0
08/09/2000 20:39	0	2.447	0	0	0.038	0
08/09/2000 20:39	0	1.657	0	0	0.013	0
08/09/2000 20:39	0	2.052	0	0	0.014	0
08/09/2000 20:39	0	1.736	0	0	0.013	0
08/09/2000 20:39	0	2.92	0	0	0.137	0
08/09/2000 20:39	0	2.052	0	0	0.027	0
08/09/2000 20:39	0	1.815	0	0	0.013	0
08/09/2000 20:39	0	1.736	0	0	0.013	0
08/09/2000 20:39	0	3.631	0	0	0.11	0
08/09/2000 20:39	0	2.605	0	0	0.03	0
08/09/2000 20:39	0	1.815	0	0	0.018	0
08/09/2000 20:39	0	1.736	0	0	0.031	0
08/09/2000 20:39	0	1.579	0	0	0.013	0
08/09/2000 20:39	0	1.657	0	0	0.013	0
08/09/2000 20:39	0	2.289	0	0	0.015	0
08/09/2000 20:39	0	1.894	0	0	0.013	0
08/09/2000 20:39	0	1.579	0	0	0.013	0
08/09/2000 20:39	0	1.973	0	0	0.055	0
08/09/2000 20:39	0	1.894	0	0	0.032	0
08/09/2000 20:39	0	3.078	0	0	0.013	0
08/09/2000 20:39	0	1.657	0	0	0.013	0
08/09/2000 20:40	0	1.657	0	0	0.013	0
08/09/2000 20:41	0	1.736	0	0	0.013	0
08/09/2000 20:41	0	4.104	0	0	0.163	0
08/09/2000 20:41	0	1.579	0	0	0.013	0
08/09/2000 20:41	0	1.657	0	0	0.013	0
08/09/2000 20:41	0	2.368	0	0	0.092	0
08/09/2000 20:41	0	2.131	0	0	0.017	0
08/09/2000 20:42	0	3.788	0	0	0.146	0
08/09/2000 20:42	0	2.762	0	0	0.039	0
08/09/2000 20:42	0	1.815	0	0	0.013	0
08/09/2000 20:42	0	1.579	0	0	0.013	0
08/09/2000 20:42	0	6.156	-1.501	0	0.156	0.011
08/09/2000 20:42	0	2.526	0	0	0.018	0
08/09/2000 20:42	0	1.815	0	0	0.013	0
08/09/2000 20:42	0	1.894	0	0	0.077	0
08/09/2000 20:42	0	1.894	0	0	0.022	0
08/09/2000 20:42	0	2.21	0	0	0.157	0
08/09/2000 20:42	0	1.815	0	0	0.013	0
08/09/2000 20:42	0	2.368	0	0	0.078	0
08/09/2000 20:42	0	1.657	0	0	0.013	0
08/09/2000 20:42	0	4.262	0	0	0.2	0
08/09/2000 20:42	0	2.289	0	0	0.027	0
08/09/2000 20:42	0	1.657	0	0	0.014	0
08/09/2000 20:43	0	1.815	0	0	0.043	0
08/09/2000 20:43	0	3.473	0	0	0.02	0
08/09/2000 20:43	0	3.078	0	0	0.106	0
08/09/2000 20:43	0	1.579	0	0	0.013	0
08/09/2000 20:43	0	1.657	0	0	0.013	0
08/09/2000 20:43	0	2.526	0	0	0.015	0

08/09/2000 20:43	0	2.447	0	0	0.142	0
08/09/2000 20:43	0	1.579	0	0	0.013	0
08/09/2000 20:43	0	2.447	-1.501	0	0.014	0.006
08/09/2000 20:43	0	1.579	0	0	0.013	0
08/09/2000 20:43	0	2.368	0	0	0.018	0
08/09/2000 20:43	0	1.657	0	0	0.013	0
08/09/2000 20:43	0	2.526	0	0	0.132	0
08/09/2000 20:43	0	1.815	0	0	0.023	0
08/09/2000 20:43	0	2.368	0	0	0.041	0
08/09/2000 20:43	0	1.736	0	0	0.013	0
08/09/2000 20:43	0	2.526	0	0	0.093	0
08/09/2000 20:43	0	2.526	0	0	0.018	0
08/09/2000 20:43	0	1.657	0	0	0.013	0
08/09/2000 20:43	0	1.815	0	0	0.013	0
08/09/2000 20:44	0	2.21	0	0	0.019	0
08/09/2000 20:44	0	1.815	0	0	0.013	0
08/09/2000 20:44	0	2.92	0	0	0.117	0
08/09/2000 20:44	0	2.762	0	0	0.024	0
08/09/2000 20:44	0	1.815	0	0	0.021	0
08/09/2000 20:44	0	3.71	0	0	0.164	0
08/09/2000 20:44	0	2.368	0	0	0.02	0
08/09/2000 20:44	0	1.657	0	0	0.013	0
08/09/2000 20:44	0	1.657	0	0	0.013	0
08/09/2000 20:44	0	1.736	0	0	0.013	0
08/09/2000 20:44	0	1.579	0	0	0.013	0
08/09/2000 20:44	0	2.052	0	0	0.038	0
08/09/2000 20:44	0	2.21	0	0	0.078	0
08/09/2000 20:44	0	3.157	0	0	0.154	0
08/09/2000 20:44	0	1.736	0	0	0.013	0
08/09/2000 20:44	0	1.736	0	0	0.013	0
08/09/2000 20:44	0	1.657	0	0	0.015	0
08/09/2000 20:44	0	1.894	0	0	0.013	0
08/09/2000 20:44	0	1.973	0	0	0.09	0
08/09/2000 20:44	0	4.578	1.659	0	0.102	0.012
08/09/2000 20:44	0	3.552	-1.58	0	0.013	0.002
08/09/2000 20:44	0	1.894	0	0	0.013	0
08/09/2000 20:45	0	3.315	0	0	0.153	0
08/09/2000 20:45	0	2.052	0	0	0.025	0
08/09/2000 20:45	0	1.736	0	0	0.013	0
08/09/2000 20:45	0	1.579	0	0	0.013	0
08/09/2000 20:45	0	2.605	0	0	0.11	0
08/09/2000 20:45	0	1.579	0	0	0.013	0
08/09/2000 20:45	0	2.999	0	0	0.111	0
08/09/2000 20:45	0	2.289	0	0	0.023	0
08/09/2000 20:45	0	1.579	0	0	0.013	0
08/09/2000 20:45	0	2.526	0	0	0.123	0
08/09/2000 20:45	0	1.657	0	0	0.013	0
08/09/2000 20:45	0	1.973	0	0	0.015	0
08/09/2000 20:45	0	3.315	0	0	0.134	0
08/09/2000 20:45	0	2.131	0	0	0.018	0
08/09/2000 20:45	0	1.657	0	0	0.013	0
08/09/2000 20:45	0	1.894	0	0	0.055	0
08/09/2000 20:45	0	2.762	0	0	0.013	0
08/09/2000 20:45	0	1.894	0	0	0.013	0
08/09/2000 20:45	0	1.815	0	0	0.019	0
08/09/2000 20:45	0	2.368	0	0	0.022	0
08/09/2000 20:45	0	1.657	0	0	0.013	0
08/09/2000 20:45	0	3.236	0	0	0.131	0
08/09/2000 20:45	0	2.131	0	0	0.029	0
08/09/2000 20:45	0	1.815	0	0	0.013	0
08/09/2000 20:45	0	3.71	0	0	0.102	0
08/09/2000 20:45	0	2.052	0	0	0.013	0
08/09/2000 20:45	0	1.657	0	0	0.014	0
08/09/2000 20:45	0	2.368	0	0	0.04	0

08/09/2000 20:45	0	1.736	0	0	0.013	0
08/09/2000 20:45	0	2.21	0	0	0.054	0
08/09/2000 20:45	0	2.684	0	0	0.013	0
08/09/2000 20:45	0	1.579	0	0	0.013	0
08/09/2000 20:45	0	2.841	0	0	0.108	0
08/09/2000 20:45	0	2.447	0	0	0.015	0
08/09/2000 20:46	0	3.157	0	0	0.132	0
08/09/2000 20:46	0	2.447	0	0	0.021	0
08/09/2000 20:46	0	2.526	0	0	0.106	0
08/09/2000 20:46	0	1.894	0	0	0.019	0
08/09/2000 20:46	0	4.262	0	0	0.129	0
08/09/2000 20:46	0	1.657	0	0	0.013	0
08/09/2000 20:46	0	1.973	0	0	0.013	0
08/09/2000 20:46	0	2.447	0	0	0.117	0
08/09/2000 20:46	0	1.736	0	0	0.013	0
08/09/2000 20:46	0	3.394	0	0	0.157	0
08/09/2000 20:46	0	2.131	0	0	0.02	0
08/09/2000 20:46	0	1.736	0	0	0.013	0
08/09/2000 20:46	0	2.605	0	0	0.025	0
08/09/2000 20:46	0	1.815	0	0	0.013	0
08/09/2000 20:46	0	1.579	0	0	0.013	0
08/09/2000 20:46	0	1.894	0	0	0.022	0
08/09/2000 20:46	0	1.657	0	0	0.013	0
08/09/2000 20:46	0	2.368	0	0	0.021	0
08/09/2000 20:46	0	1.579	0	0	0.013	0
08/09/2000 20:46	0	3.71	0	0	0.125	0
08/09/2000 20:46	0	1.894	0	0	0.013	0
08/09/2000 20:46	0	1.815	0	0	0.013	0
08/09/2000 20:46	0	1.815	0	0	0.013	0
08/09/2000 20:46	0	1.579	0	0	0.013	0
08/09/2000 20:46	0	4.578	0	0	0.142	0
08/09/2000 20:46	0	2.605	0	0	0.014	0
08/09/2000 20:46	0	1.815	0	0	0.013	0
08/09/2000 20:46	0	1.579	0	0	0.013	0
08/09/2000 20:46	0	1.894	0	0	0.03	0
08/09/2000 20:46	0	1.657	0	0	0.013	0
08/09/2000 20:46	0	5.683	0	0	0.102	0
08/09/2000 20:46	0	2.999	0	0	0.038	0
08/09/2000 20:46	0	1.815	0	0	0.013	0
08/09/2000 20:46	0	1.657	0	0	0.013	0
08/09/2000 20:46	0	1.579	0	0	0.013	0
08/09/2000 20:46	0	2.052	0	0	0.031	0
08/09/2000 20:46	0	1.579	0	0	0.013	0
08/09/2000 20:46	0	1.657	0	0	0.013	0
08/09/2000 20:46	0	1.894	0	0	0.028	0
08/09/2000 20:46	0	2.368	0	0	0.108	0
08/09/2000 20:46	0	1.815	0	0	0.013	0
08/09/2000 20:47	0	2.684	0	0	0.147	0
08/09/2000 20:47	0	1.815	0	0	0.018	0
08/09/2000 20:47	0	1.579	0	0	0.013	0
08/09/2000 20:47	0	1.736	0	0	0.013	0
08/09/2000 20:47	0	1.736	0	0	0.013	0
08/09/2000 20:47	0	2.762	0	0	0.019	0
08/09/2000 20:47	0	2.052	0	0	0.058	0
08/09/2000 20:47	0	2.131	0	0	0.047	0
08/09/2000 20:47	0	1.579	0	0	0.013	0
08/09/2000 20:47	0	1.736	0	0	0.013	0
08/09/2000 20:47	0	4.025	2.212	0	0.164	0.013
08/09/2000 20:47	0	1.815	0	0	0.013	0
08/09/2000 20:47	0	2.92	0	0	0.113	0
08/09/2000 20:47	0	1.736	0	0	0.013	0
08/09/2000 20:47	0	1.579	0	0	0.013	0
08/09/2000 20:47	0	1.894	0	0	0.013	0
08/09/2000 20:47	0	1.736	0	0	0.018	0

08/09/2000 20:47	0	2.289	0	0	0.013	0
08/09/2000 20:47	0	1.657	0	0	0.018	0
08/09/2000 20:47	0	1.815	0	0	0.035	0
08/09/2000 20:47	0	1.657	0	0	0.013	0
08/09/2000 20:47	0	1.657	0	0	0.013	0
08/09/2000 20:47	0	1.579	0	0	0.013	0
08/09/2000 20:47	0	2.447	0	0	0.09	0
08/09/2000 20:47	0	1.657	0	0	0.021	0
08/09/2000 20:47	0	4.025	0	0	0.134	0
08/09/2000 20:47	0	2.131	0	0	0.041	0
08/09/2000 20:47	0	1.579	0	0	0.013	0
08/09/2000 20:47	0	2.762	0	0	0.155	0
08/09/2000 20:47	0	1.894	0	0	0.023	0
08/09/2000 20:47	0	1.657	0	0	0.013	0
08/09/2000 20:47	0	1.815	0	0	0.037	0
08/09/2000 20:47	0	1.657	0	0	0.013	0
08/09/2000 20:48	0	4.657	0	0	0.118	0
08/09/2000 20:48	0	1.973	0	0	0.013	0
08/09/2000 20:48	0	4.972	-1.58	0	0.111	0.012
08/09/2000 20:48	0	2.841	0	0	0.032	0
08/09/2000 20:48	0	2.526	0	0	0.101	0
08/09/2000 20:48	0	2.289	0	0	0.013	0
08/09/2000 20:48	0	1.579	0	0	0.013	0
08/09/2000 20:48	0	1.579	0	0	0.013	0
08/09/2000 20:48	0	1.815	0	0	0.054	0
08/09/2000 20:48	0	1.736	0	0	0.013	0
08/09/2000 20:48	0	1.736	0	0	0.019	0
08/09/2000 20:48	0	1.815	0	0	0.018	0
08/09/2000 20:48	0	1.736	0	0	0.013	0
08/09/2000 20:48	0	1.736	0	0	0.02	0
08/09/2000 20:48	0	2.368	0	0	0.016	0
08/09/2000 20:48	0	2.605	0	0	0.152	0
08/09/2000 20:48	0	1.579	0	0	0.013	0
08/09/2000 20:48	0	1.657	0	0	0.013	0
08/09/2000 20:48	0	2.368	0	0	0.098	0
08/09/2000 20:49	0	1.579	0	0	0.013	0
08/09/2000 20:49	0	2.762	0	0	0.027	0
08/09/2000 20:49	0	1.579	0	0	0.018	0
08/09/2000 20:49	0	1.815	0	0	0.013	0
08/09/2000 20:50	0	1.973	0	0	0.013	0
08/09/2000 20:50	0	1.894	0	0	0.013	0
08/09/2000 20:50	0	1.579	0	0	0.013	0
08/09/2000 20:50	0	2.052	0	0	0.017	0
08/09/2000 20:50	0	2.841	0	0	0.151	0
08/09/2000 20:50	0	1.736	0	0	0.013	0
08/09/2000 20:50	0	1.815	0	0	0.013	0
08/09/2000 20:50	0	2.92	0	0	0.117	0
08/09/2000 20:50	0	2.21	0	0	0.014	0
08/09/2000 20:50	0	1.579	0	0	0.013	0
08/09/2000 20:50	0	1.657	0	0	0.013	0
08/09/2000 20:50	0	3.236	0	0	0.142	0
08/09/2000 20:50	0	1.736	0	0	0.015	0
08/09/2000 20:50	0	1.736	0	0	0.013	0
08/09/2000 20:50	0	1.815	0	0	0.013	0
08/09/2000 20:50	0	2.289	0	0	0.058	0
08/09/2000 20:50	0	2.052	0	0	0.04	0
08/09/2000 20:50	0	1.736	0	0	0.013	0
08/09/2000 20:50	0	2.684	0	0	0.132	0
08/09/2000 20:50	0	2.131	0	0	0.045	0
08/09/2000 20:50	0	1.736	0	0	0.013	0
08/09/2000 20:50	0	1.657	0	0	0.013	0
08/09/2000 20:50	0	1.657	0	0	0.017	0
08/09/2000 20:50	0	2.447	0	0	0.112	0
08/09/2000 20:50	0	1.579	0	0	0.013	0

08/09/2000 20:50	0	3.315	0	0	0.083	0
08/09/2000 20:50	0	2.684	0	0	0.1	0
08/09/2000 20:50	0	2.526	0	0	0.073	0
08/09/2000 20:50	0	2.289	0	0	0.027	0
08/09/2000 20:50	0	1.815	0	0	0.013	0
08/09/2000 20:51	0	1.657	0	0	0.013	0
08/09/2000 20:51	0	1.973	0	0	0.06	0
08/09/2000 20:51	0	1.657	0	0	0.013	0
08/09/2000 20:51	0	5.209	-1.975	0	0.107	0.009
08/09/2000 20:51	0	2.368	0	0	0.058	0
08/09/2000 20:51	0	1.579	0	0	0.013	0
08/09/2000 20:51	0	1.736	0	0	0.016	0
08/09/2000 20:51	0	4.183	0	0	0.115	0
08/09/2000 20:51	0	2.447	0	0	0.017	0
08/09/2000 20:51	0	1.973	0	0	0.013	0
08/09/2000 20:51	0	2.999	0	0	0.118	0
08/09/2000 20:51	0	1.973	0	0	0.015	0
08/09/2000 20:51	0	1.657	0	0	0.023	0
08/09/2000 20:51	0	2.131	0	0	0.051	0
08/09/2000 20:51	0	1.815	0	0	0.013	0
08/09/2000 20:51	0	5.367	0	0	0.123	0
08/09/2000 20:51	0	2.684	0	0	0.108	0
08/09/2000 20:51	0	1.579	0	0	0.013	0
08/09/2000 20:51	0	1.579	0	0	0.013	0
08/09/2000 20:51	0	3.236	0	0	0.102	0
08/09/2000 20:51	0	2.605	0	0	0.061	0
08/09/2000 20:51	0	1.736	0	0	0.019	0
08/09/2000 20:51	0	1.657	0	0	0.014	0
08/09/2000 20:51	0	1.815	0	0	0.024	0
08/09/2000 20:51	0	2.052	0	0	0.016	0
08/09/2000 20:51	0	1.815	0	0	0.013	0
08/09/2000 20:51	0	1.657	0	0	0.013	0
08/09/2000 20:51	0	2.92	0	0	0.013	0
08/09/2000 20:51	0	1.657	0	0	0.013	0
08/09/2000 20:51	0	1.657	0	0	0.013	0
08/09/2000 20:51	0	2.21	0	0	0.013	0
08/09/2000 20:51	0	2.447	0	0	0.101	0
08/09/2000 20:51	0	3.315	0	0	0.089	0
08/09/2000 20:51	0	2.052	0	0	0.013	0
08/09/2000 20:51	0	1.657	0	0	0.013	0
08/09/2000 20:51	0	3.394	0	0	0.104	0
08/09/2000 20:51	0	2.999	0	0	0.027	0
08/09/2000 20:51	0	3.552	0	0	0.108	0
08/09/2000 20:51	0	2.21	0	0	0.055	0
08/09/2000 20:51	0	1.579	0	0	0.013	0
08/09/2000 20:51	0	1.657	0	0	0.013	0
08/09/2000 20:52	0	2.447	0	0	0.136	0
08/09/2000 20:52	0	1.657	0	0	0.013	0
08/09/2000 20:52	0	1.973	0	0	0.013	0
08/09/2000 20:52	0	1.657	0	0	0.015	0
08/09/2000 20:52	0	1.736	0	0	0.013	0
08/09/2000 20:52	0	2.605	0	0	0.053	0
08/09/2000 20:52	0	2.21	0	0	0.038	0
08/09/2000 20:52	0	1.657	0	0	0.03	0
08/09/2000 20:52	0	1.815	0	0	0.013	0
08/09/2000 20:53	0	1.579	0	0	0.013	0
08/09/2000 20:53	0	1.579	0	0	0.013	0
08/09/2000 20:53	0	1.579	0	0	0.013	0
08/09/2000 20:53	0	1.657	0	0	0.015	0
08/09/2000 20:53	0	1.815	0	0	0.02	0
08/09/2000 20:53	0	1.657	0	0	0.015	0
08/09/2000 20:53	0	1.894	0	0	0.013	0
08/09/2000 20:53	0	1.657	0	0	0.013	0
08/09/2000 20:54	0	1.579	0	0	0.013	0

08/09/2000 20:54	0	1.736	0	0	0.013	0
08/09/2000 20:54	0	1.579	0	0	0.013	0
08/09/2000 20:54	0	3.631	-1.896	0	0.118	0.013
08/09/2000 20:54	0	3.236	0	0	0.016	0
08/09/2000 20:54	0	1.815	0	0	0.013	0
08/09/2000 20:54	0	1.973	0	0	0.024	0
08/09/2000 20:54	0	1.736	0	0	0.022	0
08/09/2000 20:54	0	1.579	0	0	0.013	0
08/09/2000 20:54	0	2.131	0	0	0.016	0
08/09/2000 20:54	0	3.157	0	0	0.125	0
08/09/2000 20:54	0	2.052	0	0	0.026	0
08/09/2000 20:54	0	1.579	0	0	0.013	0
08/09/2000 20:54	0	1.657	0	0	0.013	0
08/09/2000 20:54	0	1.973	0	0	0.124	0
08/09/2000 20:54	0	1.579	0	0	0.013	0
08/09/2000 20:54	0	2.605	0	0	0.117	0
08/09/2000 20:54	0	1.657	0	0	0.013	0
08/09/2000 20:54	0	1.736	0	0	0.013	0
08/09/2000 20:54	0	2.21	0	0	0.114	0
08/09/2000 20:54	0	1.973	0	0	0.013	0
08/09/2000 20:54	0	2.526	0	0	0.109	0
08/09/2000 20:54	0	1.815	0	0	0.018	0
08/09/2000 20:54	0	2.131	0	0	0.053	0
08/09/2000 20:54	0	2.21	0	0	0.042	0
08/09/2000 20:54	0	2.131	0	0	0.016	0
08/09/2000 20:54	0	2.131	0	0	0.013	0
08/09/2000 20:54	0	1.894	0	0	0.013	0
08/09/2000 20:54	0	1.579	0	0	0.013	0
08/09/2000 20:54	0	1.973	0	0	0.021	0
08/09/2000 20:54	0	1.579	0	0	0.013	0
08/09/2000 20:54	0	1.579	0	0	0.013	0
08/09/2000 20:54	0	2.052	0	0	0.015	0
08/09/2000 20:54	0	2.21	0	0	0.017	0
08/09/2000 20:55	0	1.736	0	0	0.013	0
08/09/2000 20:55	0	3.078	0	0	0.152	0
08/09/2000 20:55	0	1.815	0	0	0.026	0
08/09/2000 20:55	0	1.973	0	0	0.013	0
08/09/2000 20:55	0	1.657	0	0	0.013	0
08/09/2000 20:55	0	2.052	0	0	0.013	0
08/09/2000 20:55	0	2.21	0	0	0.015	0
08/09/2000 20:55	0	3.552	0	0	0.068	0
08/09/2000 20:55	0	1.894	0	0	0.013	0
08/09/2000 20:55	0	1.579	0	0	0.013	0
08/09/2000 20:55	0	3.473	0	0	0.118	0
08/09/2000 20:55	0	2.052	0	0	0.037	0
08/09/2000 20:55	0	1.657	0	0	0.013	0
08/09/2000 20:55	0	1.815	0	0	0.022	0
08/09/2000 20:55	0	2.289	0	0	0.026	0
08/09/2000 20:55	0	3.078	0	0	0.096	0
08/09/2000 20:55	0	2.21	0	0	0.015	0
08/09/2000 20:55	0	1.736	0	0	0.013	0
08/09/2000 20:55	0	1.815	0	0	0.013	0
08/09/2000 20:55	0	1.579	0	0	0.013	0
08/09/2000 20:55	0	1.973	0	0	0.018	0
08/09/2000 20:55	0	1.815	0	0	0.018	0
08/09/2000 20:55	0	1.736	0	0	0.013	0
08/09/2000 20:55	0	1.894	0	0	0.013	0
08/09/2000 20:55	0	1.736	0	0	0.013	0
08/09/2000 20:55	0	1.736	0	0	0.024	0
08/09/2000 20:55	0	2.131	0	0	0.013	0
08/09/2000 20:55	0	1.736	0	0	0.013	0
08/09/2000 20:55	0	4.104	0	0	0.099	0
08/09/2000 20:55	0	2.684	0	0	0.021	0
08/09/2000 20:55	0	1.815	0	0	0.015	0

08/09/2000 20:55	0	1.579	0	0	0.013	0
08/09/2000 20:55	0	1.657	0	0	0.019	0
08/09/2000 20:55	0	1.657	0	0	0.013	0
08/09/2000 20:55	0	1.815	0	0	0.013	0
08/09/2000 20:55	0	2.447	0	0	0.074	0
08/09/2000 20:55	0	1.579	0	0	0.013	0
08/09/2000 20:55	0	1.579	0	0	0.013	0
08/09/2000 20:55	0	1.815	0	0	0.013	0
08/09/2000 20:55	0	1.657	0	0	0.013	0
08/09/2000 20:55	0	2.289	0	0	0.093	0
08/09/2000 20:55	0	2.289	0	0	0.112	0
08/09/2000 20:55	0	4.499	0	0	0.107	0
08/09/2000 20:55	0	3.078	0	0	0.041	0
08/09/2000 20:55	0	1.736	0	0	0.013	0
08/09/2000 20:55	0	3.157	0	0	0.123	0
08/09/2000 20:55	0	2.447	0	0	0.023	0
08/09/2000 20:55	0	1.894	0	0	0.013	0
08/09/2000 20:55	0	1.736	0	0	0.013	0
08/09/2000 20:55	0	2.368	0	0	0.105	0
08/09/2000 20:55	0	2.841	0	0	0.021	0
08/09/2000 20:57	0	1.657	0	0	0.013	0
08/09/2000 20:57	0	1.579	0	0	0.013	0
08/09/2000 20:57	0	2.131	0	0	0.013	0
08/09/2000 20:57	0	1.657	0	0	0.013	0
08/09/2000 20:57	0	2.526	0	0	0.013	0
08/09/2000 20:57	0	1.973	0	0	0.013	0
08/09/2000 20:57	0	1.579	0	0	0.013	0
08/09/2000 20:57	0	1.657	0	0	0.013	0
08/09/2000 20:57	0	4.262	-1.817	0	0.093	0.009
08/09/2000 20:57	0	1.815	0	0	0.013	0
08/09/2000 20:57	0	1.579	0	0	0.013	0
08/09/2000 20:57	0	2.289	0	0	0.058	0
08/09/2000 20:57	0	1.973	0	0	0.014	0
08/09/2000 20:57	0	1.579	0	0	0.013	0
08/09/2000 20:58	0	2.526	0	0	0.023	0
08/09/2000 20:58	0	1.579	0	0	0.013	0
08/09/2000 20:58	0	1.579	0	0	0.013	0
08/09/2000 20:58	0	3.867	0	0	0.106	0
08/09/2000 20:58	0	2.605	0	0	0.04	0
08/09/2000 20:58	0	1.657	0	0	0.013	0
08/09/2000 20:58	0	1.579	0	0	0.013	0
08/09/2000 21:11	0	1.579	0	0	0.013	0
08/09/2000 21:16	0	2.92	0	0	0.155	0
08/09/2000 21:16	0	1.736	0	0	0.013	0
08/09/2000 21:17	0	2.289	0	0	0.013	0
08/09/2000 21:34	0	1.736	0	0	0.013	0
08/09/2000 21:34	0	2.605	0	0	0.059	0
08/09/2000 21:34	0	2.21	0	0	0.031	0
08/09/2000 21:34	0	2.447	0	0	0.149	0
08/09/2000 21:34	0	1.736	0	0	0.013	0
08/09/2000 21:34	0	1.579	0	0	0.013	0
08/09/2000 21:34	0	1.657	0	0	0.013	0
08/09/2000 21:34	0	1.815	0	0	0.049	0
08/09/2000 21:35	0	2.684	0	0	0.149	0
08/09/2000 21:35	0	1.894	0	0	0.016	0
08/09/2000 21:35	0	1.657	0	0	0.013	0
08/09/2000 21:38	0	1.579	0	0	0.013	0
08/09/2000 21:38	0	1.579	0	0	0.014	0
08/09/2000 21:38	0	1.815	0	0	0.013	0
08/09/2000 21:38	0	1.815	0	0	0.013	0
08/09/2000 21:39	0	1.973	0	0	0.142	0
08/09/2000 21:39	0	1.579	0	0	0.013	0
08/09/2000 21:40	0	1.579	0	0	0.013	0
08/09/2000 21:40	0	2.289	0	0	0.067	0

08/09/2000 21:42	0	1.894	0	0	0.013	0
08/09/2000 21:42	0	1.973	0	0	0.1	0
08/09/2000 21:44	0	1.579	0	0	0.013	0
08/09/2000 21:44	0	1.657	0	0	0.014	0
08/09/2000 21:44	0	1.579	0	0	0.013	0
08/09/2000 21:44	0	1.657	0	0	0.023	0
08/09/2000 21:44	0	1.736	0	0	0.013	0
08/09/2000 21:47	0	2.289	0	0	0.123	0

NSW RIB Shock Data

(data taken during routine training op using IST Snapshock data recorder)

	Shock Magnitude (Gs)			Shock Duration (sec)		
Date/Time of Shock Event:	Long (x-axis)	Vertical (z-axis)	Lateral (y-axis)	Long (x-axis)	Vertical (z-axis)	Lateral (y-axis)
08/09/2000 11:39	0	1.101	0	0	0.176	0
08/09/2000 11:40	0	1.651	0	0	0.377	0
08/09/2000 11:41	0	1.336	0	0	0.262	0
08/09/2000 11:41	0	1.101	0	0	0.152	0
08/09/2000 11:41	0	1.179	0	0	0.238	0
08/09/2000 11:41	0	2.123	0	0	0.744	0
08/09/2000 11:41	0	1.572	0	0	0.431	0
08/09/2000 11:41	0	1.101	0	0	0.117	0
08/09/2000 11:41	0	1.494	0	0	0.195	0
08/09/2000 11:41	0	1.651	0	0	0.248	0
08/09/2000 11:42	0	1.101	0	0	0.194	0
08/09/2000 11:42	0	1.336	0	0	0.23	0
08/09/2000 11:42	0	1.336	0	0	0.204	0
08/09/2000 11:42	0	1.73	0	0	0.347	0
08/09/2000 11:43	0	1.258	0	0	0.277	0
08/09/2000 11:43	0	1.494	0	0	0.248	0
08/09/2000 11:43	0	1.101	0	0	0.108	0
08/09/2000 11:44	0	1.808	0	0	0.28	0
08/09/2000 11:44	0	1.415	0	0	0.278	0
08/09/2000 11:44	0	1.022	0	0	0.198	0
08/09/2000 11:44	0	-1.101	0	0	0.184	0
08/09/2000 11:44	0	1.808	0	0	0.352	0
08/09/2000 11:44	0	0.943	0	0	0.159	0
08/09/2000 11:44	0	2.437	0.868	0	0.637	0.013
08/09/2000 11:44	0	1.572	0	0	0.259	0
08/09/2000 11:49	0	1.887	0	0	0.253	0
08/09/2000 11:49	0	2.673	0	0	0.507	0
08/09/2000 11:49	0	2.123	0	0	0.831	0
08/09/2000 11:49	0	2.044	0	0	0.537	0
08/09/2000 11:49	0	2.909	0.789	0	0.429	0.012
08/09/2000 11:49	0	1.965	0	0	0.716	0
08/09/2000 11:49	0	2.358	0	0	1.01	0
08/09/2000 11:49	0	2.201	0	0	0.466	0
08/09/2000 11:49	0	1.179	0	0	0.317	0
08/09/2000 11:49	0	1.258	0	0	0.221	0
08/09/2000 11:49	0	2.673	0	0	0.701	0
08/09/2000 11:49	0	2.358	0	0	0.509	0
08/09/2000 11:49	0	3.459	0	0	0.553	0
08/09/2000 11:49	0	1.179	0	0	0.196	0
08/09/2000 11:49	0	1.336	0	0	0.215	0
08/09/2000 11:49	0	1.101	0	0	0.339	0
08/09/2000 11:49	0	1.336	0	0	0.227	0
08/09/2000 11:49	0	1.415	0	0	0.316	0
08/09/2000 11:49	0	2.28	0	0	0.423	0
08/09/2000 11:49	0	1.494	0	0	0.14	0
08/09/2000 11:49	0	1.179	0	0	0.343	0
08/09/2000 11:49	0	-1.572	0	0	0.853	0
08/09/2000 11:49	0	1.73	0	0	0.136	0
08/09/2000 11:49	0	-1.258	0	0	0.307	0
08/09/2000 11:49	0	1.572	0	0	0.118	0
08/09/2000 11:49	0	1.022	0	0	0.213	0
08/09/2000 11:49	0	1.179	0	0	0.259	0

08/09/2000 11:50	0	1.887	0.789	0	0.557	0.013
08/09/2000 11:50	0	1.73	0	0	0.574	0
08/09/2000 11:50	0	1.415	0	0	0.192	0
08/09/2000 11:50	0	1.258	0	0	0.453	0
08/09/2000 11:50	0	1.494	0	0	0.442	0
08/09/2000 11:50	0	1.022	0	0	0.117	0
08/09/2000 11:50	0	2.123	0	0	0.647	0
08/09/2000 11:50	0	2.123	-0.789	0	0.494	0.013
08/09/2000 11:50	0	1.101	0	0	0.255	0
08/09/2000 11:50	0	4.167	0	0	0.595	0
08/09/2000 11:50	0	3.931	0	0	0.605	0
08/09/2000 11:50	0	1.415	0	0	0.087	0
08/09/2000 11:50	0	1.336	0	0	0.397	0
08/09/2000 11:50	0	1.415	0	0	0.173	0
08/09/2000 11:50	0	2.044	0	0	0.387	0
08/09/2000 11:50	0	1.808	0	0	0.723	0
08/09/2000 11:50	0	1.494	0	0	0.53	0
08/09/2000 11:50	0	2.044	0	0	0.608	0
08/09/2000 11:50	0	2.437	0	0	0.518	0
08/09/2000 11:50	0	1.73	0	0	0.092	0
08/09/2000 11:50	0	1.415	0	0	0.396	0
08/09/2000 11:50	0	2.987	0	0	0.714	0
08/09/2000 11:50	0	1.101	0	0	0.155	0
08/09/2000 11:50	0	1.494	0	0	0.422	0
08/09/2000 11:50	0	2.437	0	0	0.664	0
08/09/2000 11:50	0	3.616	0.789	0	0.587	0.007
08/09/2000 11:50	0	1.572	0	0	0.673	0
08/09/2000 11:50	0	1.258	0	0	0.13	0
08/09/2000 11:50	0	2.752	0	0	0.482	0
08/09/2000 11:50	0	1.73	0	0	0.172	0
08/09/2000 11:51	0	2.752	0	0	0.534	0
08/09/2000 11:51	0	1.179	0	0	0.114	0
08/09/2000 11:51	0	1.415	0	0	0.293	0
08/09/2000 11:51	0	2.28	0	0	0.252	0
08/09/2000 11:51	0	1.101	0	0	0.15	0
08/09/2000 11:51	0	1.022	0	0	0.199	0
08/09/2000 11:51	0	4.324	-1.263	0	0.539	0.013
08/09/2000 11:51	0	1.022	0	0	0.11	0
08/09/2000 11:51	0	1.808	0	0	0.259	0
08/09/2000 11:51	0	1.651	0	0	0.132	0
08/09/2000 11:51	0	1.179	0	0	0.23	0
08/09/2000 11:51	0	3.931	0	0	0.538	0
08/09/2000 11:51	0	2.358	0	0	0.497	0
08/09/2000 11:51	0	1.179	0	0	0.207	0
08/09/2000 11:51	0	1.415	0	0	0.396	0
08/09/2000 11:51	0	2.909	0	0	0.788	0
08/09/2000 11:51	0	3.459	0	0	0.664	0
08/09/2000 11:51	0	2.201	0	0	0.071	0
08/09/2000 11:51	0	1.336	0	0	0.228	0
08/09/2000 11:51	0	1.101	0	0	0.183	0
08/09/2000 11:51	0	1.808	0	0	0.584	0
08/09/2000 11:51	0	3.302	0	0	0.505	0
08/09/2000 11:51	0	1.887	0	0	0.47	0
08/09/2000 11:51	0	1.336	0	0	0.16	0
08/09/2000 11:51	0	2.358	0	0	0.529	0
08/09/2000 11:51	0	2.83	0	0	0.472	0
08/09/2000 11:51	0	-1.179	0	0	0.353	0
08/09/2000 11:51	0	1.808	0	0	0.151	0
08/09/2000 11:51	0	2.358	0	0	0.609	0
08/09/2000 11:51	0	3.145	0	0	0.423	0
08/09/2000 11:51	0	2.673	-0.789	0	0.489	0.013
08/09/2000 11:51	0	2.987	0	0	0.329	0
08/09/2000 11:51	0	1.258	0	0	0.314	0
08/09/2000 11:51	0	1.651	0	0	0.25	0

08/09/2000 11:51	0	1.101	0	0	0.185	0
08/09/2000 11:51	0	1.179	0	0	0.153	0
08/09/2000 11:51	0	3.223	0	0	0.618	0
08/09/2000 11:51	0	4.245	0	0	0.589	0
08/09/2000 11:51	0	1.651	0	0	0.288	0
08/09/2000 11:51	0	1.651	0	0	0.279	0
08/09/2000 11:51	0	2.909	0	0	0.367	0
08/09/2000 11:51	0	1.965	0	0	0.408	0
08/09/2000 11:51	0	1.336	0	0	0.257	0
08/09/2000 11:52	0	1.808	0	0	0.457	0
08/09/2000 11:52	0	2.28	0	0	0.675	0
08/09/2000 11:52	0	1.258	0	0	0.167	0
08/09/2000 11:52	0	1.336	0	0	0.091	0
08/09/2000 11:52	0	1.415	0	0	0.121	0
08/09/2000 11:52	0	1.572	0	0	0.5	0
08/09/2000 11:52	0	2.123	0	0	0.636	0
08/09/2000 11:52	0	2.437	0	0	0.308	0
08/09/2000 11:52	0	1.73	0	0	0.433	0
08/09/2000 11:52	0	3.381	0	0	0.526	0
08/09/2000 11:52	0.948	5.818	-2.052	0.013	0.562	0.046
08/09/2000 11:52	0	2.987	0.789	0	0.669	0.009
08/09/2000 11:52	0	1.101	0	0	0.27	0
08/09/2000 11:52	0	2.123	0	0	0.258	0
08/09/2000 11:52	0	1.101	0	0	0.148	0
08/09/2000 11:52	0	2.123	0	0	0.512	0
08/09/2000 11:52	0	2.437	0	0	0.423	0
08/09/2000 11:52	0	1.965	0	0	0.297	0
08/09/2000 11:52	0	1.258	0	0	0.284	0
08/09/2000 11:52	0	1.808	0	0	0.228	0
08/09/2000 11:52	0	1.258	0	0	0.363	0
08/09/2000 11:52	0	-1.258	0	0	0.512	0
08/09/2000 11:52	0	2.28	0	0	0.077	0
08/09/2000 11:52	0	1.572	0	0	0.167	0
08/09/2000 11:52	0	2.437	0	0	0.351	0
08/09/2000 11:52	0	2.673	0	0	0.513	0
08/09/2000 11:52	0	1.179	0	0	0.324	0
08/09/2000 11:52	0	1.415	0	0	0.216	0
08/09/2000 11:52	0	1.572	0	0	0.301	0
08/09/2000 11:52	0	2.83	-0.789	0	0.365	0.007
08/09/2000 11:52	0	1.73	0	0	0.366	0
08/09/2000 11:52	0	1.808	0	0	0.256	0
08/09/2000 11:52	0	1.494	0	0	0.101	0
08/09/2000 11:52	0	1.73	0	0	0.456	0
08/09/2000 11:52	0	1.336	0	0	0.337	0
08/09/2000 11:52	0	3.695	-0.789	0	0.59	0.013
08/09/2000 11:52	0	4.56	1.105	0	0.534	0.013
08/09/2000 11:52	0	-1.258	0	0	0.537	0
08/09/2000 11:52	0	2.516	0	0	0.158	0
08/09/2000 11:52	0	1.887	0	0	0.454	0
08/09/2000 11:52	0	1.808	0	0	0.333	0
08/09/2000 11:52	0	2.516	0	0	0.656	0
08/09/2000 11:53	0	4.088	0.789	0	0.491	0.013
08/09/2000 11:53	0	3.774	0	0	0.785	0
08/09/2000 11:53	0	1.101	0	0	0.283	0
08/09/2000 11:53	0	2.28	0	0	0.217	0
08/09/2000 11:53	0	1.651	0	0	0.521	0
08/09/2000 11:53	0	1.258	0	0	0.156	0
08/09/2000 11:53	0	3.223	0	0	0.65	0
08/09/2000 11:53	0	4.009	0.789	0	0.535	0.009
08/09/2000 11:53	0	1.179	0	0	0.213	0
08/09/2000 11:53	0	1.258	0	0	0.341	0
08/09/2000 11:53	0	1.494	0	0	0.275	0
08/09/2000 11:53	0	1.887	0	0	0.364	0
08/09/2000 11:53	0	1.651	0	0	0.085	0

08/09/2000 11:53	0	1.808	0	0	0.248	0
08/09/2000 11:53	0	1.651	0	0	0.187	0
08/09/2000 11:53	0	1.965	0	0	0.262	0
08/09/2000 11:53	0	1.808	0	0	0.535	0
08/09/2000 11:53	0	1.572	0	0	0.342	0
08/09/2000 11:53	0	-1.101	0	0	0.372	0
08/09/2000 11:53	0	1.808	0.947	0	0.13	0.013
08/09/2000 11:53	0	1.494	0	0	0.159	0
08/09/2000 11:53	0	1.965	0	0	0.083	0
08/09/2000 11:53	0	1.101	0	0	0.162	0
08/09/2000 11:53	0	-1.101	0	0	0.283	0
08/09/2000 11:53	0	1.808	0	0	0.115	0
08/09/2000 11:53	0	1.572	0	0	0.133	0
08/09/2000 11:53	0	1.494	0	0	0.107	0
08/09/2000 11:53	0	1.258	0	0	0.188	0
08/09/2000 11:53	0	1.258	0	0	0.108	0
08/09/2000 11:53	0	1.179	0	0	0.156	0
08/09/2000 11:53	0	1.336	0	0	0.377	0
08/09/2000 11:53	0	2.516	0	0	0.473	0
08/09/2000 11:53	0	1.572	0	0	0.164	0
08/09/2000 11:53	0	3.145	-0.789	0	0.408	0.006
08/09/2000 11:53	0	2.123	0	0	0.407	0
08/09/2000 11:53	0	2.044	0	0	0.218	0
08/09/2000 11:53	0	1.808	0	0	0.639	0
08/09/2000 11:53	0	1.494	0	0	0.285	0
08/09/2000 11:53	0	2.594	0	0	0.58	0
08/09/2000 11:53	0.79	2.987	0	0.013	0.411	0
08/09/2000 11:53	0	1.101	0	0	0.127	0
08/09/2000 11:53	0	2.594	0	0	0.433	0
08/09/2000 11:53	0	3.145	0	0	0.513	0
08/09/2000 11:53	0	1.415	0	0	0.249	0
08/09/2000 11:53	0	1.258	0	0	0.294	0
08/09/2000 11:54	0	-1.73	0	0	0.793	0
08/09/2000 11:54	0	3.695	0	0	0.074	0
08/09/2000 11:54	0	2.516	0	0	0.575	0
08/09/2000 11:54	0	1.336	0	0	0.144	0
08/09/2000 11:54	0	-1.415	0	0	0.747	0
08/09/2000 11:54	0	2.594	-0.947	0	0.157	0.014
08/09/2000 11:54	0	-1.258	0	0	0.695	0
08/09/2000 11:54	0.79	3.695	0	0.008	0.078	0
08/09/2000 11:54	0	1.415	0	0	0.094	0
08/09/2000 11:54	0	2.201	0.789	0	0.47	0.013
08/09/2000 11:54	0	1.887	0	0	0.25	0
08/09/2000 11:54	0	1.336	0	0	0.789	0
08/09/2000 11:54	0	1.73	0	0	0.25	0
08/09/2000 11:54	0	1.179	0	0	0.279	0
08/09/2000 11:54	0	2.987	0	0	0.431	0
08/09/2000 11:54	0	1.336	0	0	0.114	0
08/09/2000 11:54	0	1.572	0	0	0.24	0
08/09/2000 11:54	0	1.808	0	0	0.222	0
08/09/2000 11:54	0	1.73	0	0	0.384	0
08/09/2000 11:54	0	2.673	0	0	0.35	0
08/09/2000 11:54	0	1.494	0	0	0.537	0
08/09/2000 11:54	0	1.887	0	0	0.569	0
08/09/2000 11:54	0	1.101	0	0	0.138	0
08/09/2000 11:54	0	3.459	0	0	0.552	0
08/09/2000 11:54	0	1.415	0	0	0.513	0
08/09/2000 11:54	0	1.808	0	0	0.082	0
08/09/2000 11:54	0	1.73	0	0	0.203	0
08/09/2000 11:54	0	3.459	0	0	0.418	0
08/09/2000 11:54	0	2.909	0	0	0.273	0
08/09/2000 11:54	0	2.437	0	0	0.683	0
08/09/2000 11:55	0	4.088	1.026	0	0.585	0.013
08/09/2000 11:55	0	1.651	0	0	0.429	0

08/09/2000 11:55	0	2.28	0	0	0.458	0
08/09/2000 11:55	0	-1.415	0	0	0.637	0
08/09/2000 11:55	0	2.437	0	0	0.127	0
08/09/2000 11:55	0	2.201	0	0	0.147	0
08/09/2000 11:55	0	1.415	0	0	0.191	0
08/09/2000 11:55	0	3.223	-1.026	0	0.653	0.014
08/09/2000 11:55	0	2.594	0	0	0.854	0
08/09/2000 11:55	0	1.494	0	0	0.654	0
08/09/2000 11:55	0	3.931	0	0	0.642	0
08/09/2000 11:55	0	1.808	0	0	0.53	0
08/09/2000 11:55	0	2.358	0	0	0.853	0
08/09/2000 11:55	0	3.223	0	0	0.726	0
08/09/2000 11:55	0	1.336	0	0	0.303	0
08/09/2000 11:55	0.79	2.516	0	0.013	0.608	0
08/09/2000 11:55	0	4.245	0	0	0.631	0
08/09/2000 11:55	0	1.022	0	0	0.121	0
08/09/2000 11:55	0	1.651	0	0	1.109	0
08/09/2000 11:55	0	1.651	0	0	0.558	0
08/09/2000 11:55	0	2.83	0	0	0.518	0
08/09/2000 11:55	0	3.616	0.947	0	0.572	0.011
08/09/2000 11:55	0	2.987	0.789	0	0.565	0.008
08/09/2000 11:55	0	2.28	0	0	0.776	0
08/09/2000 11:55	0	1.415	0	0	0.466	0
08/09/2000 11:55	0.79	3.145	0.868	0.001	0.431	0.013
08/09/2000 11:55	0	1.494	0	0	0.243	0
08/09/2000 11:55	0	1.651	0	0	0.348	0
08/09/2000 11:55	0	1.101	0	0	0.18	0
08/09/2000 11:55	0	3.695	0.789	0	0.563	0.01
08/09/2000 11:55	0	2.752	0	0	0.803	0
08/09/2000 11:55	0	1.572	0	0	0.378	0
08/09/2000 11:55	0	3.223	0	0	0.617	0
08/09/2000 11:55	0	2.28	0	0	0.167	0
08/09/2000 11:55	0	1.572	0	0	0.674	0
08/09/2000 11:55	0	1.73	0	0	0.083	0
08/09/2000 11:55	0	1.651	0	0	0.473	0
08/09/2000 11:55	0	2.28	0	0	0.938	0
08/09/2000 11:55	0	2.358	0	0	0.38	0
08/09/2000 11:56	0	1.336	0	0	0.459	0
08/09/2000 11:56	0	1.179	0	0	0.138	0
08/09/2000 11:56	0	1.179	0	0	0.276	0
08/09/2000 11:56	0	1.572	0	0	0.312	0
08/09/2000 11:56	0	1.494	0	0	0.472	0
08/09/2000 11:56	0	1.73	0	0	0.259	0
08/09/2000 11:56	0	1.965	0	0	0.617	0
08/09/2000 11:56	0	4.953	0	0	0.637	0
08/09/2000 11:56	0	3.538	0	0	0.639	0
08/09/2000 11:56	0	1.258	0	0	0.129	0
08/09/2000 11:56	0	1.336	0	0	0.172	0
08/09/2000 11:56	0	2.752	0	0	0.257	0
08/09/2000 11:56	0	1.258	0	0	0.138	0
08/09/2000 11:56	0	1.651	0	0	0.089	0
08/09/2000 11:56	0	2.044	0	0	0.464	0
08/09/2000 11:56	0	2.044	0	0	0.61	0
08/09/2000 11:56	0	1.494	0	0	0.502	0
08/09/2000 11:56	0	1.336	0	0	0.832	0
08/09/2000 11:56	0	2.437	-0.868	0	0.605	0.013
08/09/2000 11:56	0	1.415	0	0	0.224	0
08/09/2000 11:56	0	1.336	0	0	0.248	0
08/09/2000 11:56	0	3.223	-0.789	0	0.289	0.007
08/09/2000 11:56	0	2.516	0	0	0.399	0
08/09/2000 11:56	0	-1.258	0	0	0.659	0
08/09/2000 11:56	0.79	5.267	1.026	0.001	0.117	0.013
08/09/2000 11:56	0	5.267	0	0	0.493	0
08/09/2000 11:56	0	1.336	0	0	0.471	0

08/09/2000 11:56	0	1.179	0	0	0.11	0
08/09/2000 11:56	0	1.808	0	0	0.859	0
08/09/2000 11:56	0	1.572	0	0	0.523	0
08/09/2000 11:56	0	2.83	-0.789	0	0.678	0.013
08/09/2000 11:56	0	4.324	0	0	0.564	0
08/09/2000 11:56	0	1.808	0	0	0.25	0
08/09/2000 11:56	0.79	4.638	1.263	0.001	0.762	0.02
08/09/2000 11:56	0	2.673	0	0	0.736	0
08/09/2000 11:56	0	1.808	0	0	0.177	0
08/09/2000 11:57	0	1.336	0	0	0.155	0
08/09/2000 11:57	0	1.179	0	0	0.128	0
08/09/2000 11:57	0	2.123	0	0	0.73	0
08/09/2000 11:57	0	3.538	0	0	0.637	0
08/09/2000 11:57	0	1.808	0	0	0.669	0
08/09/2000 11:57	0	2.516	0	0	0.419	0
08/09/2000 11:57	0	1.887	0	0	0.27	0
08/09/2000 11:57	0	1.022	0	0	0.149	0
08/09/2000 11:57	0	1.336	0	0	0.281	0
08/09/2000 11:57	0	2.28	0	0	0.629	0
08/09/2000 11:57	0	2.752	0	0	0.539	0
08/09/2000 11:57	0	0.943	0	0	0.111	0
08/09/2000 11:57	0	1.965	0	0	0.725	0
08/09/2000 11:57	0	2.358	0	0	0.521	0
08/09/2000 11:57	0	1.336	0	0	0.301	0
08/09/2000 11:57	0	1.73	0	0	0.349	0
08/09/2000 11:57	0	1.73	0	0	0.583	0
08/09/2000 11:57	0	2.044	-0.868	0	0.401	0.013
08/09/2000 11:57	0	-1.179	0	0	0.221	0
08/09/2000 11:57	0	1.101	0	0	0.109	0
08/09/2000 11:57	0	1.415	0	0	0.287	0
08/09/2000 11:57	0	2.752	0	0	0.534	0
08/09/2000 11:57	0	1.965	0	0	0.317	0
08/09/2000 11:57	0	2.909	0	0	0.613	0
08/09/2000 11:57	0	1.258	0	0	0.257	0
08/09/2000 11:57	0	3.302	0	0	0.712	0
08/09/2000 11:57	0.869	4.796	0.868	0.001	0.266	0.013
08/09/2000 11:57	0	1.572	0	0	0.197	0
08/09/2000 11:57	0	3.381	0	0	0.293	0
08/09/2000 11:57	0	1.651	0	0	0.428	0
08/09/2000 11:57	0	1.651	0	0	0.431	0
08/09/2000 11:57	0	1.887	0	0	0.653	0
08/09/2000 11:57	0	1.494	0	0	0.239	0
08/09/2000 11:57	0	1.336	0	0	0.43	0
08/09/2000 11:57	0	2.987	0	0	0.71	0
08/09/2000 11:57	0	3.538	0	0	0.566	0
08/09/2000 11:57	0	3.066	0.868	0	0.417	0.013
08/09/2000 11:57	0.869	5.346	-0.868	0.011	0.415	0.013
08/09/2000 11:58	0	1.494	0	0	0.161	0
08/09/2000 11:58	0	1.887	0	0	0.477	0
08/09/2000 11:58	0	2.673	0	0	0.742	0
08/09/2000 11:58	0	1.022	0	0	0.144	0
08/09/2000 11:58	0	1.415	0	0	0.141	0
08/09/2000 11:58	0	1.101	0	0	0.187	0
08/09/2000 11:58	0	1.494	0	0	0.389	0
08/09/2000 11:58	0	2.201	0	0	0.606	0
08/09/2000 11:58	0	2.123	0	0	0.547	0
08/09/2000 11:58	0	2.044	0	0	0.553	0
08/09/2000 11:58	0	3.145	0	0	0.596	0
08/09/2000 11:58	0	1.572	0	0	0.138	0
08/09/2000 11:58	0	1.101	0	0	0.311	0
08/09/2000 11:58	0	1.101	0	0	0.363	0
08/09/2000 11:58	0	1.494	0	0	0.138	0
08/09/2000 11:58	0	1.651	0	0	0.149	0
08/09/2000 11:58	0	1.101	0	0	0.224	0

08/09/2000 11:58	0	1.258	0	0	0.096	0
08/09/2000 11:58	0	1.965	0	0	0.732	0
08/09/2000 11:58	0	3.381	0.947	0	0.671	0.013
08/09/2000 11:58	0	1.179	0	0	0.314	0
08/09/2000 11:58	0	1.415	0	0	0.336	0
08/09/2000 11:58	0	2.594	0.789	0	0.808	0.013
08/09/2000 11:58	0	1.415	0	0	0.233	0
08/09/2000 11:58	0	1.651	0	0	0.562	0
08/09/2000 11:58	0	2.044	0	0	0.618	0
08/09/2000 11:58	0	1.258	0	0	0.237	0
08/09/2000 11:58	0	2.123	0	0	0.586	0
08/09/2000 11:58	0	2.044	0	0	0.655	0
08/09/2000 11:58	0	1.179	0	0	0.25	0
08/09/2000 11:58	0	2.044	0	0	0.687	0
08/09/2000 11:58	0	2.594	0	0	0.425	0
08/09/2000 11:59	0	1.572	0	0	0.125	0
08/09/2000 11:59	0	1.808	0	0	0.485	0
08/09/2000 11:59	0	2.044	0	0	0.263	0
08/09/2000 11:59	0	4.245	0	0	0.488	0
08/09/2000 11:59	0	2.909	0	0	0.362	0
08/09/2000 11:59	0	1.258	0	0	0.455	0
08/09/2000 11:59	0	2.437	0	0	0.355	0
08/09/2000 11:59	0	1.101	0	0	0.175	0
08/09/2000 11:59	0	1.336	0	0	0.467	0
08/09/2000 11:59	0	1.887	0	0	0.158	0
08/09/2000 11:59	0	1.494	0	0	0.479	0
08/09/2000 11:59	0	1.494	0	0	0.618	0
08/09/2000 11:59	0	1.572	0	0	0.559	0
08/09/2000 11:59	0	1.572	0	0	0.102	0
08/09/2000 11:59	0	1.494	0	0	0.454	0
08/09/2000 11:59	0	1.808	0	0	0.655	0
08/09/2000 11:59	0	2.28	0	0	0.756	0
08/09/2000 11:59	0.869	3.538	-0.789	0.001	0.566	0.013
08/09/2000 11:59	0	3.066	0.947	0	0.851	0.013
08/09/2000 11:59	0	2.987	0.789	0	0.611	0.013
08/09/2000 11:59	0	2.044	0	0	0.497	0
08/09/2000 11:59	0	1.258	0	0	0.164	0
08/09/2000 11:59	0	1.258	0	0	0.546	0
08/09/2000 11:59	0	3.381	0	0	0.773	0
08/09/2000 11:59	0	1.572	0	0	0.673	0
08/09/2000 11:59	0	1.887	0	0	0.692	0
08/09/2000 11:59	0	1.494	0	0	0.444	0
08/09/2000 11:59	0	2.83	0	0	0.559	0
08/09/2000 11:59	0	2.358	0	0	0.069	0
08/09/2000 11:59	0	1.572	0	0	0.44	0
08/09/2000 11:59	0	2.358	-0.868	0	0.402	0.009
08/09/2000 11:59	0	1.258	0	0	0.424	0
08/09/2000 11:59	0	1.022	0	0	0.11	0
08/09/2000 11:59	0	1.572	0	0	0.306	0
08/09/2000 11:59	0	1.73	0	0	0.123	0
08/09/2000 12:00	0	3.774	0.789	0	0.527	0.013
08/09/2000 12:00	0	1.022	0	0	0.159	0
08/09/2000 12:00	0	1.887	0	0	0.538	0
08/09/2000 12:00	0	1.179	0	0	0.14	0
08/09/2000 12:00	0	1.808	0	0	0.083	0
08/09/2000 12:00	0	1.415	0	0	0.18	0
08/09/2000 12:00	0	1.336	0	0	0.144	0
08/09/2000 12:00	0	1.965	0	0	0.602	0
08/09/2000 12:00	0	2.909	0	0	0.472	0
08/09/2000 12:00	0	2.987	-0.789	0	0.433	0.013
08/09/2000 12:00	0	3.616	-0.789	0	0.522	0.013
08/09/2000 12:00	0	2.594	-0.868	0	0.442	0.013
08/09/2000 12:00	0	1.494	0	0	0.314	0
08/09/2000 12:00	0	2.044	0	0	0.312	0

08/09/2000 12:00	0	-1.336	0	0	0.608	0
08/09/2000 12:00	0	1.651	0	0	0.402	0
08/09/2000 12:00	0	2.28	0	0	0.066	0
08/09/2000 12:00	0	1.494	0	0	0.31	0
08/09/2000 12:00	0	-1.179	0	0	0.453	0
08/09/2000 12:00	0	2.201	-0.868	0	0.228	0.013
08/09/2000 12:00	0	1.415	0	0	0.424	0
08/09/2000 12:00	0	2.358	0	0	0.502	0
08/09/2000 12:00	0	1.808	0	0	0.623	0
08/09/2000 12:00	0	1.965	0	0	0.538	0
08/09/2000 12:00	0	2.594	-0.789	0	0.714	0.013
08/09/2000 12:00	0	2.28	0	0	0.091	0
08/09/2000 12:00	0	1.808	0	0	0.343	0
08/09/2000 12:00	0	1.101	0	0	0.215	0
08/09/2000 12:00	0	1.415	0	0	0.302	0
08/09/2000 12:00	0	1.965	0	0	0.491	0
08/09/2000 12:00	0	1.887	0	0	0.438	0
08/09/2000 12:00	0	1.651	0	0	0.35	0
08/09/2000 12:00	0.79	5.503	1.026	0.001	0.588	0.013
08/09/2000 12:00	0.948	5.267	0.789	0.013	0.596	0.008
08/09/2000 12:01	0	1.651	0	0	0.477	0
08/09/2000 12:01	0	1.651	0	0	0.106	0
08/09/2000 12:01	0	1.415	0	0	0.13	0
08/09/2000 12:01	0	1.101	0	0	0.232	0
08/09/2000 12:01	0	1.73	0	0	0.158	0
08/09/2000 12:01	0	1.258	0	0	0.642	0
08/09/2000 12:01	-0.79	8.569	2.999	0.001	0.064	0.028
08/09/2000 12:01	0	2.987	-1.657	0	0.361	0.013
08/09/2000 12:01	0	1.022	0	0	0.137	0
08/09/2000 12:01	0	1.494	0	0	0.376	0
08/09/2000 12:01	0	1.022	0	0	0.11	0
08/09/2000 12:01	0	1.572	0	0	0.158	0
08/09/2000 12:01	0	2.044	0	0	0.458	0
08/09/2000 12:01	0	2.123	0	0	0.556	0
08/09/2000 12:01	0	2.123	0	0	0.515	0
08/09/2000 12:01	0	2.044	0	0	0.599	0
08/09/2000 12:01	0	1.572	0	0	0.303	0
08/09/2000 12:01	0	1.651	0	0	0.693	0
08/09/2000 12:01	0	1.965	0	0	0.65	0
08/09/2000 12:01	0	3.066	0.789	0	0.626	0.008
08/09/2000 12:01	0	1.179	0	0	0.286	0
08/09/2000 12:01	0	2.437	0	0	0.812	0
08/09/2000 12:01	0	2.516	0	0	0.62	0
08/09/2000 12:01	0	1.258	0	0	0.327	0
08/09/2000 12:01	0	1.808	0	0	0.152	0
08/09/2000 12:01	0	1.494	0	0	0.239	0
08/09/2000 12:01	0	2.28	0	0	0.267	0
08/09/2000 12:01	0	1.415	0	0	0.287	0
08/09/2000 12:01	0	1.336	0	0	0.145	0
08/09/2000 12:01	0	3.616	-1.342	0	0.629	0.016
08/09/2000 12:01	0	3.381	0.868	0	0.428	0.009
08/09/2000 12:01	0	1.494	0	0	0.181	0
08/09/2000 12:01	0	1.022	0	0	0.212	0
08/09/2000 12:02	0	1.179	0	0	0.104	0
08/09/2000 12:02	0	1.101	0	0	0.162	0
08/09/2000 12:02	0	1.572	0	0	0.119	0
08/09/2000 12:02	0	1.258	0	0	0.177	0
08/09/2000 12:02	0	1.258	0	0	0.132	0
08/09/2000 12:02	0	1.022	0	0	0.109	0
08/09/2000 12:02	0	1.336	0	0	0.271	0
08/09/2000 12:02	0	1.651	0	0	0.227	0
08/09/2000 12:03	0	1.887	0	0	0.572	0
08/09/2000 12:03	0	1.651	0	0	0.23	0
08/09/2000 12:03	0	1.651	0	0	0.108	0

08/09/2000 12:03	0	1.415	0	0	0.18	0
08/09/2000 12:03	0	1.965	0	0	0.504	0
08/09/2000 12:03	0	1.179	0	0	0.208	0
08/09/2000 12:03	0	1.336	0	0	0.32	0
08/09/2000 12:03	0	1.336	0	0	0.216	0
08/09/2000 12:03	0	1.572	0	0	0.404	0
08/09/2000 12:03	0	1.73	0	0	0.486	0
08/09/2000 12:03	0	1.965	0	0	0.455	0
08/09/2000 12:03	0	1.179	0	0	0.168	0
08/09/2000 12:04	0	1.494	0	0	0.467	0
08/09/2000 12:04	0	1.887	0	0	0.605	0
08/09/2000 12:04	0	2.123	0	0	0.467	0
08/09/2000 12:04	0	1.179	0	0	0.138	0
08/09/2000 12:04	0	1.179	0	0	0.147	0
08/09/2000 12:04	0	1.179	0	0	0.168	0
08/09/2000 12:04	0	1.179	0	0	0.099	0
08/09/2000 12:04	0	1.179	0	0	0.38	0
08/09/2000 12:04	0	1.965	0	0	0.483	0
08/09/2000 12:04	0	2.673	0	0	0.349	0
08/09/2000 12:04	0	1.73	0	0	0.193	0
08/09/2000 12:04	0.79	1.808	0	0.013	0.085	0
08/09/2000 12:04	0	1.887	0	0	0.397	0
08/09/2000 12:04	0	1.258	0	0	0.307	0
08/09/2000 12:04	0	1.651	0	0	0.089	0
08/09/2000 12:04	0	1.258	0	0	0.277	0
08/09/2000 12:04	0	1.336	0	0	0.212	0
08/09/2000 12:04	0	1.022	0	0	0.134	0
08/09/2000 12:04	0	1.572	0	0	0.184	0
08/09/2000 12:05	0	2.437	0	0	0.583	0
08/09/2000 12:05	0	2.123	0	0	0.649	0
08/09/2000 12:05	0	2.044	0	0	0.679	0
08/09/2000 12:05	0	1.494	0	0	0.233	0
08/09/2000 12:05	0	1.415	0	0	0.456	0
08/09/2000 12:05	0	2.044	0	0	0.501	0
08/09/2000 12:05	0	2.358	0	0	0.493	0
08/09/2000 12:05	0	1.179	0	0	0.271	0
08/09/2000 12:05	0	1.415	0	0	0.171	0
08/09/2000 12:05	0	1.336	0	0	0.428	0
08/09/2000 12:05	0	1.572	0	0	0.348	0
08/09/2000 12:05	0	1.651	0	0	0.662	0
08/09/2000 12:05	0	1.415	0	0	0.458	0
08/09/2000 12:06	0	1.022	0	0	0.111	0
08/09/2000 12:06	0	1.022	0	0	0.134	0
08/09/2000 12:06	0	2.044	0	0	0.565	0
08/09/2000 12:06	0	1.258	0	0	0.274	0
08/09/2000 12:06	0	1.101	0	0	0.143	0
08/09/2000 12:06	0	1.572	0	0	0.222	0
08/09/2000 12:06	0	1.336	0	0	0.205	0
08/09/2000 12:06	0	1.179	0	0	0.15	0
08/09/2000 12:06	0	1.258	0	0	0.383	0
08/09/2000 12:06	0	1.415	0	0	0.488	0
08/09/2000 12:06	0	2.123	0	0	0.483	0
08/09/2000 12:07	0	1.336	0	0	0.177	0
08/09/2000 12:07	0	2.437	0	0	0.477	0
08/09/2000 12:07	0	1.887	0	0	0.528	0
08/09/2000 12:07	0	1.336	0	0	0.257	0
08/09/2000 12:07	0	1.258	0	0	0.488	0
08/09/2000 12:07	0	1.022	0	0	0.117	0
08/09/2000 12:07	0	1.494	0	0	0.422	0
08/09/2000 12:07	0.79	1.73	0	0.013	0.23	0
08/09/2000 12:07	0	1.887	0	0	0.482	0
08/09/2000 12:07	0	1.258	0	0	0.147	0
08/09/2000 12:07	0	1.101	0	0	0.247	0
08/09/2000 12:07	0	1.101	0	0	0.222	0

08/09/2000 12:08	0	1.258	0	0	0.37	0
08/09/2000 12:08	0	1.965	0	0	0.496	0
08/09/2000 12:08	0	1.572	0	0	0.613	0
08/09/2000 12:08	0	1.179	0	0	0.26	0
08/09/2000 12:08	0	1.258	0	0	0.372	0
08/09/2000 12:08	0	1.179	0	0	0.14	0
08/09/2000 12:08	0	1.101	0	0	0.203	0
08/09/2000 12:08	0	1.808	0	0	0.633	0
08/09/2000 12:08	0	1.258	0	0	0.327	0
08/09/2000 12:08	0	1.258	0	0	0.233	0
08/09/2000 12:08	0	1.101	0	0	0.249	0
08/09/2000 12:08	0	1.101	0	0	0.168	0
08/09/2000 12:09	0	1.73	0	0	0.4	0
08/09/2000 12:09	0	1.258	0	0	0.298	0
08/09/2000 12:09	0	1.415	0	0	0.373	0
08/09/2000 12:09	0	1.651	0	0	0.482	0
08/09/2000 12:09	0	1.336	0	0	0.212	0
08/09/2000 12:09	0	1.887	0	0	0.432	0
08/09/2000 12:09	0	1.179	0	0	0.162	0
08/09/2000 12:10	0	1.415	0	0	0.415	0
08/09/2000 12:10	0	1.022	0	0	0.111	0
08/09/2000 12:10	0	1.179	0	0	0.209	0
08/09/2000 12:10	0	1.651	0	0	0.407	0
08/09/2000 12:10	0	1.336	0	0	0.357	0
08/09/2000 12:10	0	1.651	0	0	0.422	0
08/09/2000 12:10	0	1.808	0	0	0.376	0
08/09/2000 12:10	0	1.887	0	0	0.428	0
08/09/2000 12:11	0	1.258	0	0	0.228	0
08/09/2000 12:11	0	1.415	0	0	0.294	0
08/09/2000 12:11	0	1.494	0	0	0.484	0
08/09/2000 12:11	0	1.808	0	0	0.47	0
08/09/2000 12:11	0	1.494	0	0	0.202	0
08/09/2000 12:11	0	1.179	0	0	0.139	0
08/09/2000 12:11	0	1.415	0	0	0.407	0
08/09/2000 12:11	0	1.258	0	0	0.317	0
08/09/2000 12:11	0	2.123	0	0	0.541	0
08/09/2000 12:11	0	1.572	0	0	0.252	0
08/09/2000 12:11	0	1.415	0	0	0.394	0
08/09/2000 12:12	0	1.258	0	0	0.213	0
08/09/2000 12:12	0	1.179	0	0	0.298	0
08/09/2000 12:12	0	1.808	0	0	0.258	0
08/09/2000 12:12	0	1.179	0	0	0.111	0
08/09/2000 12:12	0	1.651	0	0	0.614	0
08/09/2000 12:12	0	1.73	0	0	0.077	0
08/09/2000 12:12	0	1.572	0	0	0.131	0
08/09/2000 12:12	0	1.336	0	0	0.222	0
08/09/2000 12:12	0	1.572	0	0	0.259	0
08/09/2000 12:12	0	1.494	0	0	0.549	0
08/09/2000 12:12	0	2.28	0	0	0.546	0
08/09/2000 12:12	0	1.179	0	0	0.123	0
08/09/2000 12:12	0	1.572	0	0	0.313	0
08/09/2000 12:13	0	1.965	0	0	0.428	0
08/09/2000 12:13	0	1.965	0	0	0.388	0
08/09/2000 12:13	0	2.201	0	0	0.247	0
08/09/2000 12:13	0	-1.022	0	0	0.166	0
08/09/2000 12:13	0	1.651	0	0	0.198	0
08/09/2000 12:13	0	1.651	0	0	0.472	0
08/09/2000 12:13	0	1.494	0	0	0.27	0
08/09/2000 12:13	0	-1.179	0	0	0.42	0
08/09/2000 12:13	0	1.965	0	0	0.159	0
08/09/2000 12:13	0	1.258	0	0	0.165	0
08/09/2000 12:13	0	1.336	0	0	0.368	0
08/09/2000 12:13	0	2.358	0	0	0.59	0
08/09/2000 12:13	0	-1.258	0	0	0.395	0

08/09/2000 12:13	0	-1.101	0	0	0.204	0
08/09/2000 12:13	0	2.044	0	0	0.243	0
08/09/2000 12:13	0	1.336	0	0	0.257	0
08/09/2000 12:13	0	1.494	0	0	0.282	0
08/09/2000 12:13	0	1.336	0	0	0.302	0
08/09/2000 12:14	0	1.965	0	0	0.396	0
08/09/2000 12:14	0	1.494	0	0	0.265	0
08/09/2000 12:14	0	2.594	0	0	0.552	0
08/09/2000 12:14	0	1.887	0	0	0.397	0
08/09/2000 12:14	0	1.022	0	0	0.24	0
08/09/2000 12:14	0	1.179	0	0	0.222	0
08/09/2000 12:14	0	1.494	0	0	0.391	0
08/09/2000 12:14	0	1.101	0	0	0.13	0
08/09/2000 12:14	0	1.101	0	0	0.176	0
08/09/2000 12:14	0	2.673	0.789	0	0.468	0.013
08/09/2000 12:14	0	2.673	0	0	0.777	0
08/09/2000 12:14	0	1.494	0	0	0.398	0
08/09/2000 12:14	0	1.101	-1.184	0	0.021	0.172
08/09/2000 12:14	0	1.494	1.184	0	0.529	0.013
08/09/2000 12:14	0	1.415	0	0	0.147	0
08/09/2000 12:14	0	1.336	0	0	0.267	0
08/09/2000 12:15	0	1.887	0	0	0.538	0
08/09/2000 12:16	0	1.179	0	0	0.138	0
08/09/2000 12:16	0	2.123	0	0	0.479	0
08/09/2000 12:16	0	1.258	0	0	0.283	0
08/09/2000 12:16	0	1.808	0	0	0.333	0
08/09/2000 12:16	0	1.572	0	0	0.247	0
08/09/2000 12:16	0	1.965	0	0	0.343	0
08/09/2000 12:16	0	1.336	0	0	0.268	0
08/09/2000 12:16	0	1.572	0	0	0.33	0
08/09/2000 12:16	0	1.101	0	0	0.343	0
08/09/2000 12:16	0	1.494	0	0	0.097	0
08/09/2000 12:16	0	1.494	0	0	0.426	0
08/09/2000 12:16	0	1.494	0	0	0.162	0
08/09/2000 12:16	0	1.179	0	0	0.188	0
08/09/2000 12:16	0	1.258	0	0	0.242	0
08/09/2000 12:17	0	1.415	0	0	0.289	0
08/09/2000 12:17	0	1.336	0	0	0.126	0
08/09/2000 12:17	0	1.336	0	0	0.337	0
08/09/2000 12:17	0	1.651	0	0	0.311	0
08/09/2000 12:17	0	1.101	0	0	0.129	0
08/09/2000 12:18	0	1.73	0	0	0.354	0
08/09/2000 12:18	0	1.258	0	0	0.211	0
08/09/2000 12:18	0	1.572	0	0	0.382	0
08/09/2000 12:18	0	1.336	0	0	0.233	0
08/09/2000 12:18	0	2.83	0.789	0	0.496	0.013
08/09/2000 12:18	0	1.572	0	0	0.161	0
08/09/2000 12:18	0	1.965	0	0	0.572	0
08/09/2000 12:18	0	1.808	0	0	0.384	0
08/09/2000 12:18	0	1.258	0	0	0.325	0
08/09/2000 12:18	0	1.179	0	0	0.144	0
08/09/2000 12:18	0	1.965	0	0	0.582	0
08/09/2000 12:18	0	1.415	0	0	0.085	0
08/09/2000 12:18	0	1.494	0	0	0.126	0
08/09/2000 12:18	0	2.437	-0.789	0	0.527	0.01
08/09/2000 12:18	0	1.887	0	0	0.277	0
08/09/2000 12:18	0	1.022	0	0	0.108	0
08/09/2000 12:18	0	1.336	0	0	0.322	0
08/09/2000 12:18	0	2.594	0	0	0.533	0
08/09/2000 12:18	0	1.022	0	0	0.203	0
08/09/2000 12:18	0	1.808	0	0	0.508	0
08/09/2000 12:18	0	1.179	0	0	0.149	0
08/09/2000 12:18	0	1.101	0	0	0.116	0
08/09/2000 12:18	0	1.179	0	0	0.269	0

08/09/2000 12:19	0	1.258	0	0	0.127	0
08/09/2000 12:19	0	1.101	0	0	0.257	0
08/09/2000 12:19	0	1.258	0	0	0.292	0
08/09/2000 12:19	0	-1.101	0	0	0.124	0
08/09/2000 12:19	0	1.258	0	0	0.192	0
08/09/2000 12:20	0	1.179	0	0	0.138	0
08/09/2000 12:20	0	1.258	0	0	0.11	0
08/09/2000 12:20	0	2.123	0.947	0	0.071	0.013
08/09/2000 12:21	0	1.179	0	0	0.293	0
08/09/2000 12:23	0	1.494	0	0	0.292	0
08/09/2000 12:23	0.79	3.459	0.868	0.001	0.252	0.013
08/09/2000 12:23	0	1.415	0	0	0.167	0
08/09/2000 12:23	0	1.572	0	0	0.147	0
08/09/2000 12:23	0	1.965	0	0	0.264	0
08/09/2000 12:28	0	1.258	0	0	0.125	0
08/09/2000 12:32	0	0	1.105	0	0	0.237

Appendix B

(MATLAB Programs)

MATLAB Programs

Shock Spectrum Scripts

```
%**** ss.m ***** 80798
%Release of NFESC Software.  Disclaimer: this program is furnished by
%the government and is accepted and used by the recipient with the
%express understanding the  U S Government makes no warranty, expressed
%or implied, concerning the accuracy , completeness, reliability,
%usability, or suitability for any particular purpose of the
%information and data contained in this program or furnished in
%connection therewith, and the US shall be under no liability
%whatsoever to any person by reason of any use made thereof.  The
%program belongs to the government. Therefore, the recipient
%further agrees not to assert any proprietary rights therein or to
%represent this program to anyone as other than a government program.


%Program expects to see a file 'y.txt' of accelerations in g's in the
workspace.

%create the file for (y) input acceleration.
%T=0.05; %set half sine wave period.
%A=12; %set peak input acceleration (in g's);
fs=512; %set the sampling frequency of the input file data.
%f=1/(2*T); %get acceleration pulse frequency.
t=(1:513)/fs;
y=0*(1:1000); %initialize the input file.
load y4.dat; %create input file
y(151:662)=y4;
[nr nc]=size(y);
nv=max(nr,nc);% nv= number of values in shock
%*********you must set a low frequency here
flow=1;
%*********you must set a high freq here
fhigh=5000;
%********* Now spec a SAMPLING RATE (SAMPLES/SEC.)
% fs=2000;
%*********Now set FREQS PER DECADE, (ABT 200)
fpd=200;
flowlog=log10(flow);
c2=round(flowlog)-1;
jlow=fpd*(flowlog-c2);
jstart=fix(jlow);
if(jlow ~= jstart);
     jstart=jstart+1;
end;
fstart=10.^(jstart/fpd+c2);
jstop=round(fpd*(log10(fhigh)-c2));
fstop=10^(jstop/fpd+c2);
nfreqs=jstop-jstart+1;
tpi =2*pi;
gsf=386.008;
yy=gsf*y;

%*********Insert your damping ratio here with a value for zeta
```

```
zeta= .01;
h=1./fs;
eta=sqrt(1-zeta^2);
g1=2.*zeta;
g2=1.-g1*zeta;
zmin=zeros(size(1:nfreqs)); zmax=zmin;
f=10.^((jstart:jstop)./fpd+c2);

for jj=1:nfreqs;

     wom=tpi*f(jj);
     g3=wom*h;
     g4=exp(-zeta*g3);
     a15=-g4*g4;
     g5=eta*g3;
     g6=g4/eta*sin(g5);
     chi=g4*cos(g5);
     g7=chi/g6;
     g8=-a15/g6;
     a16=2*chi;
     a11=-wom*g8;
     a12= wom*(g7-zeta);
     g9=g3*wom;
     g10=g1+g3;
     g11=g2*g6;
     g12=g9*wom;
     a24=(g1*chi+a15*g10+g11)/g12;
     a25=2/g12*(g3*chi-g11-zeta*(1+a15));
     a26=(g11+g1*(1-chi)-g3)/g12;
     a27=(g1*g7-g8*g10+g2)/g9;
     a28=(g1*g8+(g3-g1)*(g7-zeta)-1)/g9;

     z=filter([a26 a25 a24],[1 -a16 -a15],yy);

     zimax=max(z); zimin=min(z);

     z0=z(nv);
     zd0=a11*z(nv-1)+a12*z(nv)+a27*yy(nv-1)+a28*yy(nv);

     %resid finds zrmin and zrmax and is a function of:
wom,zeta,eta,z0,zd0
     b=z0;
     delt=asin(zeta);
     a=(z0*zeta+zd0/wom)/eta;
     if a == 0 & b == 0
          zrmin=0; zrmax=0;
     else
          if a == 0
               beta1=0;
          elseif b == 0
               beta1=pi/2;
          elseif (a>0 & b>0) | (a<0 & b<0)
               beta1=atan(a/b);
          else
               beta1=pi-atan(-a/b);
          end
```

```
        if beta1 < delt
            beta1=beta1+pi;
        end

        wdt1=beta1-delt;
        wdt2=wdt1+pi;
        z1=exp(-zeta*wdt1/eta)*(a*sin(wdt1)+b*cos(wdt1));
        z2=exp(-zeta*wdt2/eta)*(a*sin(wdt2)+b*cos(wdt2));
        ZZ=[z0 z1 z2];
        zrmax=max(ZZ);
        zrmin=min(ZZ);
    end

    zmin(jj)=abs(min(zimin,zrmin));svmin(jj)=wom*zmin(jj);
    zmax(jj)=max(zimax,zrmax);svmax(jj)=wom*zmax(jj);
end
%Now plot max(svmin,svmax) vs f on a log log scale

loglog(f,max(svmin,svmax))

%To apply Four Coordinate Paper grid, type:
%hold on;fourcp;hold off;
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%                                            %%%%%%%%
%%%%%%%%           SHOCK SPECTRUM GENERATOR         %%%%%%%%
%%%%%%%%                                            %%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  This program generates shock spectra for SDOF systems
%  with base excitation.
%  The program requires inputs to define the excitation pulse
%  and then generates shock spectra for several different damping
%  conditions over a range of natural frequencies

clc
clf
clear

disp(' ');
disp('=========================================================
===================');
disp(' ');
disp('  Computation of Shock Spectra for a SDOF system subject to a
base excitation pulse');
disp(' ');
disp('=========================================================
===================');
```

```
disp(' ');
disp(' ');

disp(' NOTE: To get meaningful results, use SI units ');
disp(' ');
disp(' ');

%  Program calculates response using base acceleration.  To define the
%  base excitation behavior, program will request the acceleration
pulse
%  width and the max acceleration value.

T=input('    Shock pulse width (sec)                    T: ');  %
half the period of the excitation sine wave
% A=input(' Shock Pulse Max Acceleration (m/s^2)        A: ');
Wmin=input('    Minimum Natural Frequency (Hz)          Wmin: ');
Wmax=input('    Maximum Natural Frequency (Hz)          Wmax: ');
Wn=linspace(Wmin,Wmax,101);
Zt=linspace(0,.2,5);

delta_t=2/1000;  % time increment
Wp = 3.14159/T;        %  frequency of the sine wave force
t=linspace(0,2,1001);
A=1;
a=zeros(1,1001); % initialize the input acceleration array
N=round(T/delta_t);
a(1:N) = A*sin(Wp*t(1:N));
accel = zeros(5,1000);
max_accel = zeros(5,100);
X=0;
for i=1:5;
   for j=1:100;
      Wd = Wn(j)*6.28*sqrt(1-Zt(i)*Zt(i));  %  damped natural frequency
      h = -(1/Wd)*sin(Wd*t).*exp(-Zt(i)*Wn(j)*6.28*t); % Compute the
impulse response function, h(t)
      z = conv(h,a)*delta_t;  % convolution
      rel_vel(1:1000)=0;
      rel_vel =(diff(z)./delta_t);
      accel(i,1:1000)=
((Wn(j)*6.28)^2*z(1:1000)+2*Zt(i)*Wn(j)*6.28*rel_vel(1:1000));
      D=max(abs(accel(i,:)));
      max_accel(i,j)=D;
   end
end
WnT=T.*Wn;

plot(WnT(1:100),max_accel(:,1:100)), grid
title('Shock Spectrum (0.10 sec, half sine wave shock pulse)')
xlabel('Wn (Hz)')
ylabel('Max x"/Max y"')

orient tall
```

SDOF Suspension Deck Model:

```
%
% Program uses convolution to predict the response of a
% sdof suspension system to a half sine pulse base excitation
% for a range of damping ratios at a given system frequency
%

clear all

disp(' ');
disp('==================================================================
=========');
disp(' ');
disp('  Response of a SDOF Suspension System to a Half Sine Pulse');
disp('  Base Excitation by Convolution ');
disp(' ');
disp('==================================================================
=========');
disp(' ');
disp(' ');
W=input('   Enter Suspension natural frequency (in Hz): ');

for j=1:6;

Wn=W*6.283; %convert freq to radians/sec
Zt = 0.1*j; % R/(2*M*Wn) %  damping ratio
Wd = Wn*sqrt(1-Zt*Zt);  %  damped natural frequency
Wp = 3.14159/0.05;        %  frequency of the sine wave force

T=2*pi/Wp;  %  period of the sine wave

% Now define the time axis as 25 times the length of the period of the
sine wave input
t=linspace(0,8*T,1001);  % There are 1000/(8*T) time steps per period
of input

% Compute the impulse response function, h(t).
hz = -(1/Wd)*sin(Wd*t).*exp(-Zt*Wn*t);

% define the input.
f=zeros(1,1001);

% define the sine input to last for 1/2 a period, or 20 time steps
f(1:63) = 100*sin(Wp*t(1:63));

% Compute response x(t) as the convolution of the impulse response h(t)
with
% the excitation vector f(t)
delta_t=8*T/1000;  % time increment
z = conv(hz,f)*delta_t;  %  convolution
[max_z,t_max]=max(abs(z));  % find the time and value of the maximum
response
max_z;                   % show the maximum value of the response
t_max=t_max*delta_t;     % show the time of the peak response
```

```
%compute the acceleration response%
ha = Wn*exp(-Zt*Wn*t).*(2*Zt*cos(Wd*t)+(Wn/Wd)*(1-2*Zt^2)*sin(Wd*t));
accel = conv(ha,f)*delta_t;

% Plot all results
subplot(211), plot(t,z(1:length(t))), grid
title('SDOF Response to a 50 msec half-period Sine pulse');
xlabel('Time [sec]')
ylabel('z(t)'); % = F(t)*h(t)')

hold on;

subplot(212), plot(t,accel(1:length(t))), grid
title('SDOF acceleration Response to a 50 msec half-period Sine
pulse');
xlabel('Time [sec]')
ylabel('x"(t)')

hold on;

subplot(212), plot(t,f), grid

end

orient tall
```

DRI Model

```
%
% Program calculates the Dynamic Response Index (DRI) for a given
seatpan shock
% pulse
%

clear all;
disp(' ');
disp('================================================================
====');
disp(' ');
disp(' Computation of the DRI for a given Shock pulse by
Convolution');
disp(' ');
disp('================================================================
====');
disp(' ');
disp(' ');

Wn = 52.9; % natural frequency of the DRI model in rad/sec
Zt = 0.2245; % damping ratio of the DRI model
Wd = Wn*sqrt(1-Zt*Zt);  %  damped natural frequency

t=linspace(0,1,256);  % sets the time interval for convolution

% Compute the impulse response function, h(t).

h = -(1/Wd)*sin(Wd*t).*exp(-Zt*Wn*t);

% initialize the input vector

max_z=0;
f=zeros(1,256);

% get the input shock pulse data (in g's) and convert to m/s^2
load d1x1.txt;
f(1:256)=d1x1*9.81;

% Compute response z(t) as the convolution of the impulse response h(t)
with
% the excitation vector f(t)

delta_t=1/256;  % time increment
z = conv(h,f)*delta_t;  %  convolution
[max_z,t_max]=max(abs(z));  % find the time and value of the maximum
response
max_z;                    % show the maximum value of the response
t_max=t_max*delta_t;      % show the time of the peak response

DRI_dx1=(max_z*Wn^2)/9.81 %DRI for shock at seat base

% plot(t,z);

max_z=0;
```

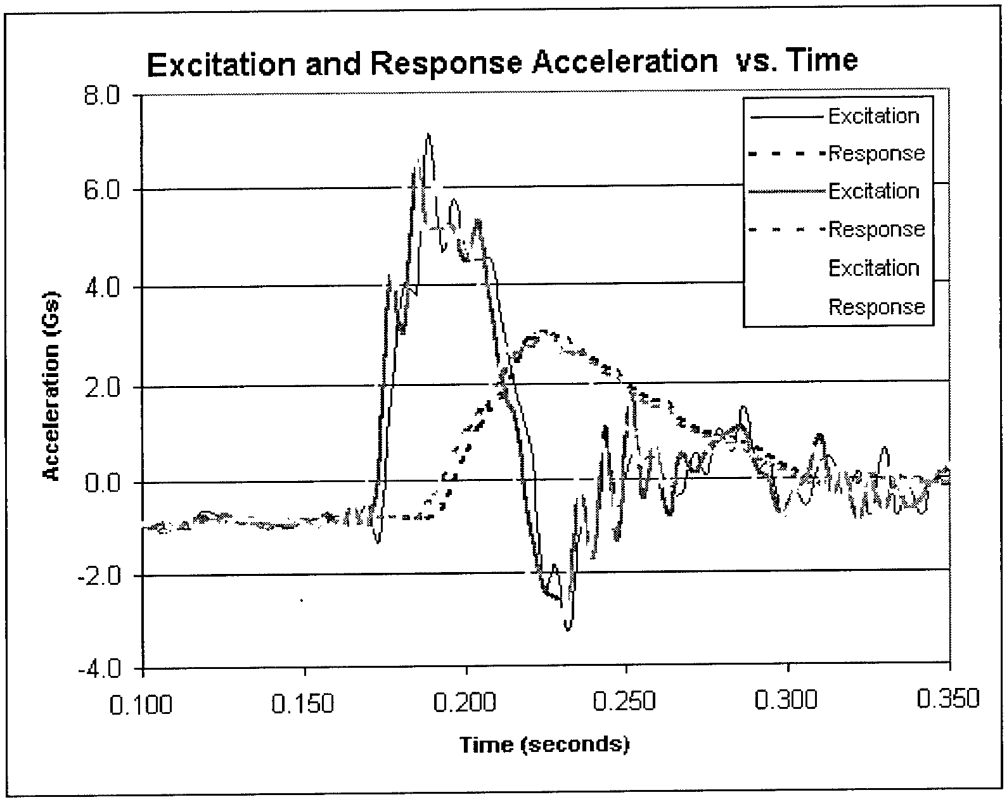
```
f=zeros(1,256);

% get the input shock pulse data (in g's) and convert to m/s^2
load d1r1.txt;
f(1:256)=d1r1*9.81;

% Compute response z(t) as the convolution of the impulse response h(t)
with
% the excitation vector f(t)

delta_t=1/256;  % time increment
z = conv(h,f)*delta_t;  %  convolution
[max_z,t_max]=max(abs(z));  % find the time and value of the maximum
response
max_z;                      % show the maximum value of the response
t_max=t_max*delta_t;        % show the time of the peak response

DRI_dr1=(max_z*Wn^2)/9.81 %DRI for shock at seat pan
```

Appendix C

(Sample Drop Table Data)

Data for 3 drops from 6 inches

(185 lb lumped mass and Medium Damping)



General Setup Parameters
Acquired data on 2 channels (1,2)
Channel 1 = Excitation, Channel 2 = Response
Acquired 256 points per channel
Sampled at 256 Hz
All channels have Engineering Units applied if relevant

Drop1

Time (sec)	Ch1 (Gs)	Ch2 (Gs)
-0.100	0.042	0.120
-0.096	0.040	0.121
-0.092	0.041	0.121

Drop2

Time (sec)	Ch1 (Gs)	Ch2 (Gs)
-0.102	0.025	-0.068
-0.098	0.025	-0.068
-0.094	0.024	-0.069

Drop3

Time (sec)	Ch1 (Gs)	Ch2 (Gs)
-0.100	0.040	0.121
-0.096	0.040	0.121
-0.092	0.040	0.121

-0.088	0.041	0.121	-0.090	0.024	-0.069	-0.088	0.041	0.121
-0.085	0.042	0.122	-0.086	0.023	-0.069	-0.085	0.038	0.121
-0.081	0.041	0.122	-0.082	0.024	-0.069	-0.081	0.039	0.122
-0.077	0.041	0.121	-0.078	0.024	-0.068	-0.077	0.038	0.121
-0.073	0.041	0.121	-0.074	0.024	-0.068	-0.073	0.040	0.121
-0.069	0.041	0.120	-0.070	0.025	-0.068	-0.069	0.040	0.121
-0.065	0.042	0.120	-0.066	0.026	-0.068	-0.065	0.040	0.120
-0.061	0.041	0.120	-0.063	0.025	-0.069	-0.061	0.039	0.120
-0.057	0.042	0.121	-0.059	0.025	-0.069	-0.057	0.040	0.120
-0.053	0.042	0.121	-0.055	0.025	-0.068	-0.053	0.040	0.120
-0.049	0.042	0.122	-0.051	0.024	-0.068	-0.049	0.041	0.121
-0.045	0.041	0.121	-0.047	0.024	-0.068	-0.045	0.042	0.121
-0.042	0.041	0.121	-0.043	0.024	-0.067	-0.042	0.042	0.121
-0.038	0.041	0.121	-0.039	0.025	-0.067	-0.038	0.042	0.122
-0.034	0.042	0.121	-0.035	0.025	-0.067	-0.034	0.040	0.122
-0.030	0.042	0.121	-0.031	0.026	-0.067	-0.030	0.040	0.122
-0.026	0.043	0.120	-0.027	0.026	-0.067	-0.026	0.040	0.122
-0.022	0.043	0.120	-0.023	0.026	-0.067	-0.022	0.041	0.122
-0.018	0.042	0.121	-0.020	0.025	-0.066	-0.018	0.041	0.122
-0.014	0.042	0.121	-0.016	0.024	-0.066	-0.014	0.041	0.123
-0.010	0.041	0.121	-0.012	0.024	-0.066	-0.010	0.041	0.123
-0.006	0.041	0.121	-0.008	0.023	-0.066	-0.006	0.041	0.122
-0.002	0.042	0.121	-0.004	0.024	-0.066	-0.002	0.041	0.122
0.001	0.043	0.122	0.000	0.026	-0.066	0.001	0.041	0.122
0.005	0.043	0.121	0.004	0.023	-0.066	0.005	0.043	0.122
0.009	0.046	0.121	0.008	0.021	-0.067	0.009	0.037	0.122
0.013	0.038	0.121	0.012	0.023	-0.067	0.013	0.046	0.122
0.017	0.057	0.122	0.016	0.027	-0.067	0.017	0.037	0.122
0.021	0.021	0.122	0.020	0.017	-0.069	0.021	0.042	0.122
0.025	0.088	0.122	0.023	0.052	-0.070	0.025	0.061	0.121
0.029	-0.009	0.123	0.027	-0.026	-0.071	0.029	0.011	0.121
0.033	0.142	0.124	0.031	0.136	-0.071	0.033	0.150	0.122
0.037	-0.059	0.127	0.035	-0.166	-0.069	0.037	-0.131	0.122
0.040	0.223	0.128	0.039	0.392	-0.067	0.040	0.387	0.126
0.044	-0.463	0.133	0.043	-2.211	-0.063	0.044	-2.521	0.131
0.048	-2.909	0.134	0.047	-2.088	-0.068	0.048	-1.736	0.118
0.052	-0.875	0.088	0.051	-0.960	-0.179	0.052	-1.008	-0.023
0.056	-1.667	-0.130	0.055	-1.838	-0.350	0.056	-1.685	-0.286
0.060	-0.926	-0.367	0.059	-0.907	-0.541	0.060	-0.774	-0.461
0.064	-1.456	-0.537	0.063	-1.790	-0.695	0.064	-1.908	-0.615
0.068	-1.437	-0.682	0.066	-0.911	-0.847	0.068	-0.956	-0.673
0.072	-1.146	-0.713	0.070	-1.439	-0.902	0.072	-1.462	-0.699
0.076	-1.401	-0.746	0.074	-1.199	-0.972	0.076	-0.797	-0.746
0.080	-0.661	-0.770	0.078	-0.752	-0.978	0.080	-0.642	-0.705
0.083	-0.610	-0.713	0.082	-1.073	-0.963	0.083	-1.109	-0.756
0.087	-0.955	-0.769	0.086	-0.755	-0.984	0.087	-0.799	-0.824
0.091	-0.744	-0.828	0.090	-0.752	-1.007	0.091	-0.706	-0.816
0.095	-0.697	-0.815	0.094	-0.782	-1.094	0.095	-0.759	-0.895

0.099	-0.890	-0.899	0.098	-0.766	-1.142	0.099	-0.937	-0.962
0.103	-0.940	-0.985	0.102	-0.919	-1.189	0.103	-0.963	-0.983
0.107	-1.150	-0.975	0.105	-0.574	-1.172	0.107	-0.877	-0.995
0.111	-0.975	-1.015	0.109	-1.002	-1.149	0.111	-0.961	-0.970
0.115	-0.994	-0.967	0.113	-0.701	-1.108	0.115	-0.840	-0.914
0.119	-0.656	-0.900	0.117	-1.068	-1.076	0.119	-0.757	-0.905
0.123	-0.727	-0.906	0.121	-0.874	-1.078	0.123	-0.844	-0.895
0.126	-0.755	-0.887	0.125	-1.002	-1.075	0.126	-0.740	-0.899
0.130	-0.861	-0.907	0.129	-0.819	-1.088	0.130	-0.886	-0.934
0.134	-0.823	-0.940	0.133	-0.844	-1.089	0.134	-0.806	-0.915
0.138	-1.021	-0.907	0.137	-0.831	-1.085	0.138	-1.031	-0.914
0.142	-0.957	-0.904	0.141	-0.849	-1.090	0.142	-0.894	-0.907
0.146	-1.009	-0.891	0.145	-0.876	-1.084	0.146	-0.988	-0.862
0.150	-0.866	-0.856	0.148	-0.844	-1.070	0.150	-0.855	-0.857
0.154	-0.836	-0.842	0.152	-1.024	-1.066	0.154	-1.016	-0.837
0.158	-0.906	-0.828	0.156	-0.827	-1.050	0.158	-0.732	-0.812
0.162	-0.753	-0.817	0.160	-1.207	-1.049	0.162	-0.926	-0.825
0.165	-0.999	-0.814	0.164	-0.449	-1.038	0.165	-0.581	-0.809
0.169	-0.512	-0.800	0.168	-1.360	-1.013	0.169	-0.990	-0.807
0.173	-1.267	-0.793	0.172	1.488	-1.007	0.173	0.136	-0.820
0.177	1.745	-0.806	0.176	4.468	-1.027	0.177	4.129	-0.816
0.181	4.042	-0.825	0.180	3.957	-1.003	0.181	3.067	-0.813
0.185	3.855	-0.841	0.184	7.237	-0.977	0.185	6.455	-0.789
0.189	7.138	-0.845	0.188	5.035	-0.643	0.189	5.244	-0.519
0.193	4.724	-0.597	0.191	6.128	-0.109	0.193	5.150	0.024
0.197	5.756	-0.028	0.195	4.853	0.463	0.197	5.187	0.576
0.201	4.649	0.609	0.199	5.114	0.891	0.201	4.486	1.084
0.205	4.516	1.132	0.203	4.368	1.229	0.205	5.281	1.396
0.208	4.522	1.486	0.207	2.645	1.713	0.208	3.587	1.645
0.212	2.918	1.816	0.211	0.961	2.281	0.212	1.866	2.230
0.216	1.706	2.416	0.215	0.166	2.912	0.216	1.154	2.583
0.220	0.693	2.894	0.219	-1.639	2.988	0.220	-1.079	2.714
0.224	-2.391	3.002	0.223	-3.448	2.997	0.224	-2.274	2.960
0.228	-1.861	2.998	0.227	-2.781	2.762	0.228	-2.532	2.877
0.232	-3.232	2.842	0.230	-3.102	2.542	0.232	-2.485	2.604
0.236	-1.058	2.659	0.234	-0.021	2.324	0.236	-0.328	2.624
0.240	-1.611	2.517	0.238	-1.729	2.014	0.240	-1.661	2.442
0.244	0.621	2.344	0.242	0.795	1.670	0.244	1.072	2.238
0.248	-0.614	2.201	0.246	-1.068	1.311	0.248	-1.335	2.040
0.251	0.474	1.951	0.250	1.773	1.111	0.251	1.771	1.819
0.255	0.408	1.778	0.254	0.324	0.984	0.255	-0.410	1.626
0.259	0.418	1.636	0.258	0.818	0.946	0.259	0.652	1.537
0.263	-0.139	1.515	0.262	-0.190	0.857	0.263	-0.806	1.379
0.267	-0.362	1.288	0.266	0.742	0.781	0.267	0.475	1.141
0.271	0.511	1.103	0.270	0.565	0.769	0.271	0.093	1.039
0.275	0.057	1.001	0.273	0.675	0.765	0.275	0.563	0.894
0.279	1.023	0.907	0.277	0.546	0.817	0.279	0.773	0.827
0.283	0.560	0.832	0.281	0.632	0.801	0.283	0.963	0.755

0.287	1.479	0.777
0.290	0.229	0.650
0.294	0.313	0.483
0.298	-0.797	0.339
0.302	-0.342	0.210
0.306	-0.565	0.056
0.310	0.353	-0.090
0.314	0.377	-0.168
0.318	-0.465	-0.189
0.322	0.123	-0.140
0.326	-0.794	-0.128
0.330	0.623	-0.063
0.333	-0.804	0.009
0.337	-0.211	-0.041
0.341	-0.817	-0.048
0.345	0.079	-0.063
0.349	-0.192	-0.131
0.353	0.149	-0.163
0.357	-0.149	-0.181
0.361	-0.359	-0.184
0.365	-0.085	-0.081
0.369	0.527	-0.066
0.373	0.958	-0.060
0.376	-0.213	-0.015
0.380	-0.368	-0.105
0.384	0.040	-0.025
0.388	0.119	0.063
0.392	0.369	0.056
0.396	-0.023	0.056
0.400	0.109	0.039
0.404	0.224	0.062
0.408	-0.254	0.046
0.412	-0.062	0.057
0.415	-0.188	0.058
0.419	-0.146	0.005
0.423	0.456	-0.022
0.427	-0.138	-0.018
0.431	0.357	-0.073
0.435	0.014	-0.071
0.439	0.183	-0.079
0.443	-0.104	-0.074
0.447	-0.222	-0.047
0.451	0.001	-0.019
0.455	-0.024	0.013
0.458	0.261	0.039
0.462	0.148	0.078
0.466	0.242	0.090
0.470	-0.040	0.117

0.285	0.595	0.720
0.289	0.083	0.523
0.293	-0.585	0.311
0.297	-0.850	0.080
0.301	-0.693	-0.111
0.305	0.203	-0.282
0.309	0.581	-0.378
0.313	-0.477	-0.450
0.316	0.304	-0.423
0.320	-1.372	-0.402
0.324	0.031	-0.295
0.328	-1.037	-0.306
0.332	0.252	-0.326
0.336	-0.405	-0.330
0.340	0.237	-0.352
0.344	-0.042	-0.318
0.348	0.373	-0.361
0.352	0.079	-0.380
0.355	-0.566	-0.362
0.359	-0.346	-0.314
0.363	0.569	-0.272
0.367	0.528	-0.182
0.371	0.425	-0.186
0.375	0.149	-0.153
0.379	0.053	-0.125
0.383	-0.288	-0.052
0.387	-0.010	-0.037
0.391	-0.201	-0.034
0.395	0.048	-0.062
0.398	-0.164	-0.110
0.402	0.411	-0.123
0.406	0.228	-0.154
0.410	0.025	-0.148
0.414	0.050	-0.176
0.418	-0.141	-0.176
0.422	-0.246	-0.202
0.426	0.251	-0.213
0.430	-0.316	-0.244
0.434	0.443	-0.246
0.438	-0.059	-0.268
0.441	0.207	-0.257
0.445	-0.149	-0.239
0.449	-0.131	-0.230
0.453	-0.054	-0.194
0.457	-0.112	-0.179
0.461	0.266	-0.126
0.465	-0.056	-0.111
0.469	0.047	-0.051

0.287	1.041	0.593
0.290	0.205	0.460
0.294	-0.050	0.324
0.298	-0.860	0.185
0.302	-0.251	0.073
0.306	0.035	-0.058
0.310	0.875	-0.162
0.314	-0.347	-0.188
0.318	0.062	-0.159
0.322	-0.890	-0.090
0.326	-0.148	0.014
0.330	-0.693	-0.013
0.333	-0.103	-0.061
0.337	-0.690	-0.028
0.341	-0.457	-0.126
0.345	-0.023	-0.119
0.349	0.096	-0.106
0.353	0.181	-0.167
0.357	-0.271	-0.186
0.361	-0.482	-0.154
0.365	0.085	-0.084
0.369	0.554	-0.062
0.373	0.838	-0.027
0.376	0.252	-0.029
0.380	-0.358	-0.071
0.384	-0.046	0.027
0.388	0.032	0.068
0.392	0.364	0.074
0.396	0.074	0.099
0.400	0.027	0.033
0.404	-0.049	0.069
0.408	0.117	0.066
0.412	0.139	0.038
0.415	-0.308	0.060
0.419	0.025	0.030
0.423	-0.296	0.002
0.427	0.727	-0.003
0.431	-0.521	-0.022
0.435	0.654	-0.041
0.439	-0.477	-0.047
0.443	0.451	-0.071
0.447	-0.267	-0.052
0.451	-0.102	-0.044
0.455	0.002	-0.003
0.458	-0.036	0.020
0.462	0.285	0.043
0.466	-0.001	0.086
0.470	0.340	0.112

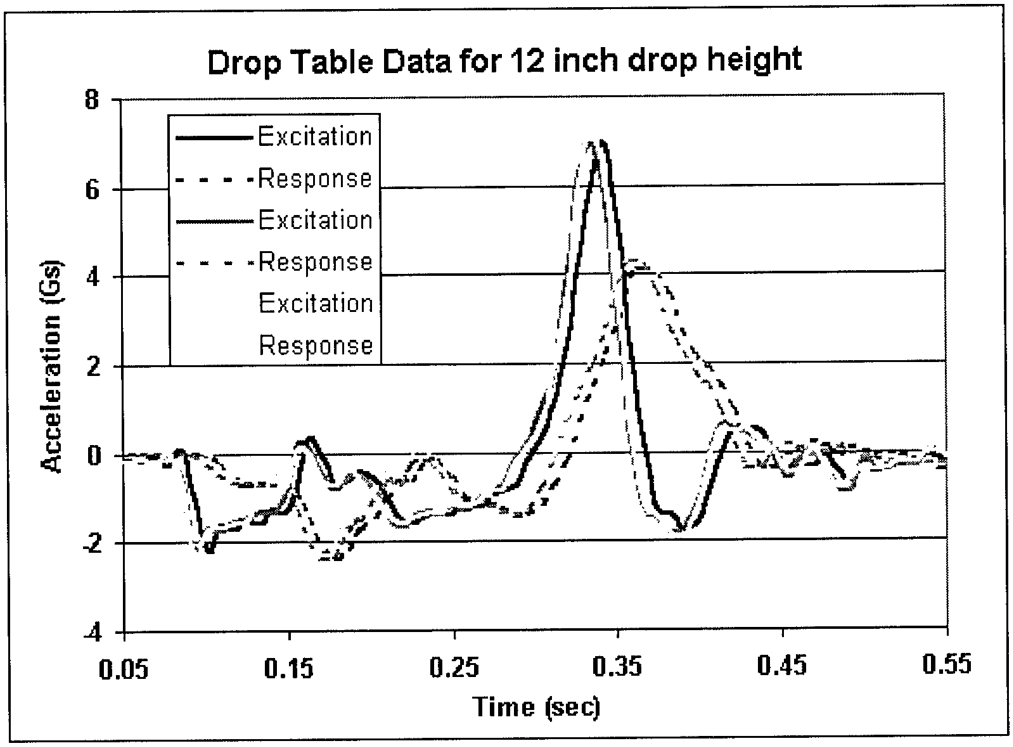
0.474	0.002	0.146	0.473	-0.192	-0.044	0.474	-0.231	0.139
0.478	-0.078	0.158	0.477	0.352	0.017	0.478	0.020	0.168
0.482	0.007	0.158	0.480	-0.004	0.019	0.482	-0.019	0.196
0.486	0.021	0.147	0.484	0.045	0.004	0.486	0.199	0.202
0.490	-0.024	0.131	0.488	-0.054	-0.028	0.490	0.085	0.189
0.494	0.169	0.138	0.492	-0.037	-0.021	0.494	0.044	0.161
0.498	0.108	0.143	0.496	-0.141	-0.051	0.498	-0.054	0.151
0.501	0.023	0.142	0.500	0.270	-0.047	0.501	-0.017	0.177
0.505	0.021	0.153	0.504	0.219	-0.023	0.505	0.111	0.174
0.509	0.007	0.160	0.508	0.093	-0.031	0.509	-0.019	0.177
0.513	-0.147	0.140	0.512	-0.046	-0.038	0.513	0.122	0.163
0.517	0.091	0.126	0.516	-0.086	-0.035	0.517	-0.019	0.131
0.521	-0.011	0.128	0.520	-0.005	-0.047	0.521	0.056	0.127
0.525	0.253	0.113	0.523	-0.081	-0.063	0.525	0.038	0.101
0.529	0.039	0.108	0.527	-0.031	-0.076	0.529	0.053	0.104
0.533	-0.069	0.121	0.531	0.002	-0.089	0.533	0.059	0.111
0.537	0.001	0.130	0.535	0.063	-0.080	0.537	-0.139	0.091
0.540	0.017	0.122	0.539	0.090	-0.080	0.540	-0.017	0.116
0.544	0.066	0.127	0.543	0.066	-0.081	0.544	0.154	0.121
0.548	0.115	0.118	0.547	0.093	-0.083	0.548	0.100	0.118
0.552	0.061	0.117	0.551	0.054	-0.088	0.552	0.101	0.135
0.556	0.084	0.130	0.555	-0.035	-0.090	0.556	0.025	0.126
0.560	0.026	0.123	0.559	-0.036	-0.088	0.560	0.006	0.126
0.564	0.058	0.139	0.563	0.007	-0.088	0.564	0.059	0.145
0.568	-0.026	0.144	0.566	0.056	-0.084	0.568	0.114	0.132
0.572	-0.054	0.135	0.570	0.044	-0.087	0.572	0.065	0.127
0.576	-0.037	0.140	0.574	0.035	-0.082	0.576	-0.007	0.119
0.580	0.021	0.120	0.578	-0.006	-0.081	0.580	-0.051	0.109
0.583	0.079	0.104	0.582	0.129	-0.077	0.583	0.018	0.105
0.587	0.130	0.090	0.586	-0.011	-0.071	0.587	0.079	0.085
0.591	0.203	0.073	0.590	0.055	-0.073	0.591	0.073	0.077
0.595	0.025	0.071	0.594	-0.040	-0.073	0.595	-0.014	0.070
0.599	0.018	0.069	0.598	-0.045	-0.081	0.599	-0.027	0.071
0.603	-0.041	0.073	0.602	-0.017	-0.091	0.603	0.049	0.072
0.607	0.021	0.079	0.605	-0.041	-0.112	0.607	0.032	0.060
0.611	0.009	0.079	0.609	0.030	-0.135	0.611	0.029	0.049
0.615	0.067	0.071	0.613	-0.024	-0.161	0.615	0.036	0.034
0.619	0.041	0.059	0.617	-0.023	-0.170	0.619	0.007	0.027
0.623	0.022	0.055	0.621	0.014	-0.177	0.623	-0.005	0.033
0.626	0.019	0.053	0.625	0.022	-0.162	0.626	0.036	0.038
0.630	-0.022	0.051	0.629	0.047	-0.144	0.630	0.048	0.054
0.634	-0.020	0.061	0.633	0.026	-0.118	0.634	0.061	0.084
0.638	-0.037	0.082	0.637	0.028	-0.094	0.638	0.007	0.110
0.642	0.048	0.107	0.641	0.017	-0.080	0.642	0.031	0.137
0.646	0.075	0.129	0.645	-0.006	-0.072	0.646	0.055	0.151
0.650	0.111	0.141	0.648	-0.022	-0.062	0.650	0.026	0.154
0.654	0.063	0.151	0.652	-0.021	-0.055	0.654	0.017	0.160
0.658	0.029	0.159	0.656	0.017	-0.039	0.658	-0.001	0.160

0.662	0.024	0.163	0.660	-0.024	-0.024	0.662	0.012	0.173
0.665	-0.001	0.167	0.664	0.055	-0.012	0.665	0.018	0.185
0.669	0.001	0.176	0.668	0.039	-0.004	0.669	0.040	0.181
0.673	0.047	0.185	0.672	0.087	0.002	0.673	0.078	0.184
0.677	0.069	0.186	0.676	0.019	-0.002	0.677	0.081	0.177
0.681	0.081	0.189	0.680	0.032	0.000	0.681	0.041	0.171
0.685	0.088	0.181	0.684	0.054	-0.004	0.685	0.053	0.169
0.689	0.068	0.168	0.688	0.069	-0.004	0.689	0.104	0.160
0.693	0.059	0.163	0.691	0.100	-0.007	0.693	0.101	0.156
0.697	0.042	0.147	0.695	0.068	-0.015	0.697	0.130	0.155
0.701	0.079	0.137	0.699	0.083	-0.026	0.701	0.070	0.153
0.705	0.074	0.134	0.703	0.048	-0.039	0.705	0.060	0.148
0.708	0.062	0.121	0.707	0.012	-0.055	0.708	0.068	0.138
0.712	0.100	0.122	0.711	0.015	-0.070	0.712	-0.012	0.118
0.716	0.029	0.117	0.715	0.027	-0.084	0.716	0.025	0.103
0.720	0.068	0.103	0.719	0.044	-0.100	0.720	0.062	0.086
0.724	0.014	0.094	0.723	0.017	-0.111	0.724	0.064	0.068
0.728	0.035	0.074	0.727	0.058	-0.122	0.728	0.020	0.060
0.732	0.048	0.058	0.730	0.056	-0.127	0.732	0.062	0.052
0.736	0.050	0.048	0.734	-0.005	-0.123	0.736	0.068	0.051
0.740	0.049	0.042	0.738	-0.010	-0.118	0.740	0.020	0.063
0.744	-0.001	0.049	0.742	-0.006	-0.108	0.744	0.018	0.068
0.748	0.032	0.059	0.746	0.013	-0.097	0.748	0.008	0.077
0.751	0.014	0.070	0.750	0.029	-0.092	0.751	0.036	0.080
0.755	0.032	0.081	0.754	0.017	-0.090	0.755	0.040	0.078
0.759	0.014	0.091	0.758	0.039	-0.096	0.759	0.027	0.084
0.763	0.023	0.096	0.762	0.038	-0.102	0.763	0.043	0.089
0.767	0.050	0.096	0.766	0.042	-0.105	0.767	0.048	0.098
0.771	0.033	0.097	0.770	0.036	-0.101	0.771	0.031	0.110
0.775	0.041	0.102	0.773	0.024	-0.088	0.775	0.024	0.122
0.779	0.059	0.112	0.777	0.006	-0.071	0.779	0.017	0.139
0.783	0.069	0.127	0.781	0.004	-0.055	0.783	0.042	0.148
0.787	0.050	0.140	0.785	0.017	-0.045	0.787	0.028	0.152
0.790	0.036	0.148	0.789	0.024	-0.042	0.790	0.034	0.156
0.794	0.010	0.156	0.793	0.027	-0.045	0.794	0.038	0.153
0.798	0.037	0.161	0.797	0.018	-0.048	0.798	0.043	0.148
0.802	-0.006	0.163	0.801	0.013	-0.049	0.802	0.036	0.151
0.806	0.052	0.167	0.805	-0.001	-0.051	0.806	0.047	0.151
0.810	0.050	0.166	0.809	0.016	-0.049	0.810	0.019	0.153
0.814	0.071	0.178	0.813	0.027	-0.046	0.814	0.073	0.161
0.818	0.025	0.173	0.816	0.052	-0.043	0.818	0.046	0.163
0.822	0.049	0.155	0.820	0.044	-0.044	0.822	0.040	0.171
0.826	0.057	0.169	0.824	0.027	-0.046	0.826	0.012	0.155
0.830	0.082	0.154	0.828	0.002	-0.047	0.830	0.077	0.144
0.833	0.004	0.143	0.832	-0.003	-0.044	0.833	0.010	0.149
0.837	-0.011	0.155	0.836	0.033	-0.040	0.837	0.092	0.123
0.841	0.069	0.134	0.840	0.028	-0.039	0.841	0.005	0.119
0.845	0.023	0.117	0.844	0.040	-0.042	0.845	0.061	0.119

0.849	0.141	0.108	0.848	0.051	-0.052	0.849	0.067	0.095
0.853	0.051	0.076	0.852	0.032	-0.065	0.853	0.030	0.096
0.857	0.093	0.067	0.855	0.034	-0.076	0.857	0.085	0.096
0.861	-0.009	0.069	0.859	0.013	-0.087	0.861	0.016	0.085
0.865	0.001	0.067	0.863	0.017	-0.091	0.865	0.023	0.105
0.869	0.018	0.090	0.867	0.012	-0.088	0.869	0.003	0.104
0.873	0.037	0.102	0.871	0.021	-0.082	0.873	0.026	0.102
0.876	0.045	0.111	0.875	0.026	-0.082	0.876	0.017	0.110
0.880	0.032	0.114	0.879	0.020	-0.087	0.880	0.037	0.098
0.884	0.086	0.102	0.883	0.019	-0.095	0.884	0.039	0.094
0.888	0.014	0.094	0.887	0.001	-0.103	0.888	0.066	0.093
0.892	0.031	0.084	0.891	-0.003	-0.105	0.892	0.053	0.088
0.896	-0.011	0.090	0.895	0.010	-0.103	0.896	0.006	0.096

Data for 3 drops from 12 inches

195 lb lumped mass and Medium Damping



General Setup Parameters
Acquired data on 2 channels (1,2)
Channel 1 = Excitation, Channel 2 = Response
Acquired 128 points per channel
Sampled at 128 Hz
All channels have Engineering Units applied if relevant

Drop1			Drop2			Drop3		
Time (sec)	Ch1 (Gs)	Ch2 (Gs)	Time (sec)	Ch1 (Gs)	Ch2 (Gs)	Time (sec)	Ch1 (Gs)	Ch2 (Gs)
-0.102	-0.161	-0.024	-0.102	-0.160	-0.019	-0.102	-0.160	0.223
-0.094	-0.161	-0.024	-0.094	-0.160	-0.019	-0.094	-0.161	0.223
-0.086	-0.161	-0.024	-0.086	-0.161	-0.020	-0.086	-0.161	0.222

-0.078	-0.160	-0.024
-0.070	-0.160	-0.024
-0.063	-0.161	-0.024
-0.055	-0.161	-0.024
-0.047	-0.160	-0.024
-0.039	-0.160	-0.024
-0.031	-0.160	-0.024
-0.023	-0.160	-0.024
-0.016	-0.160	-0.024
-0.008	-0.160	-0.024
0.000	-0.160	-0.024
0.008	-0.160	-0.024
0.016	-0.159	-0.024
0.023	-0.159	-0.024
0.031	-0.162	-0.024
0.039	-0.154	-0.024
0.047	-0.174	-0.023
0.055	-0.134	-0.024
0.063	-0.202	-0.022
0.070	-0.079	-0.025
0.078	-0.273	-0.020
0.086	0.082	-0.021
0.094	-0.945	-0.009
0.102	-2.212	-0.021
0.109	-1.628	-0.287
0.117	-1.720	-0.522
0.125	-1.504	-0.717
0.133	-1.567	-0.702
0.141	-1.273	-0.726
0.148	-1.322	-0.724
0.156	-0.693	-0.911
0.164	0.334	-1.485
0.172	-0.123	-2.166
0.180	-0.705	-2.387
0.188	-0.600	-2.136
0.195	-0.431	-1.674
0.203	-0.586	-1.421
0.211	-1.002	-0.992
0.219	-1.504	-0.663
0.227	-1.592	-0.583
0.234	-1.391	-0.193
0.242	-1.403	-0.232
0.250	-1.366	-0.577
0.258	-1.206	-0.940
0.266	-1.211	-1.109
0.273	-0.992	-1.135
0.281	-0.886	-1.240
0.289	-0.727	-1.381

-0.078	-0.160	-0.020
-0.070	-0.160	-0.020
-0.063	-0.160	-0.020
-0.055	-0.160	-0.019
-0.047	-0.160	-0.019
-0.039	-0.160	-0.018
-0.031	-0.160	-0.018
-0.023	-0.160	-0.018
-0.016	-0.160	-0.018
-0.008	-0.160	-0.018
0.000	-0.160	-0.019
0.008	-0.160	-0.019
0.016	-0.158	-0.019
0.023	-0.164	-0.020
0.031	-0.152	-0.020
0.039	-0.176	-0.020
0.047	-0.133	-0.020
0.055	-0.200	-0.019
0.063	-0.087	-0.018
0.070	-0.246	-0.017
0.078	0.002	-0.009
0.086	-0.565	-0.012
0.094	-2.179	0.007
0.102	-1.687	-0.227
0.109	-1.753	-0.476
0.117	-1.549	-0.654
0.125	-1.512	-0.680
0.133	-1.308	-0.704
0.141	-1.360	-0.723
0.148	-0.899	-0.829
0.156	0.211	-1.335
0.164	0.135	-2.095
0.172	-0.511	-2.378
0.180	-0.806	-2.262
0.188	-0.498	-1.729
0.195	-0.487	-1.483
0.203	-0.828	-1.067
0.211	-1.358	-0.663
0.219	-1.683	-0.708
0.227	-1.468	-0.252
0.234	-1.322	-0.170
0.242	-1.396	-0.509
0.250	-1.186	-0.861
0.258	-1.291	-1.081
0.266	-1.063	-1.108
0.273	-0.856	-1.189
0.281	-0.719	-1.317
0.289	-0.122	-1.400

-0.078	-0.160	0.222
-0.070	-0.160	0.222
-0.063	-0.161	0.221
-0.055	-0.160	0.222
-0.047	-0.160	0.222
-0.039	-0.160	0.222
-0.031	-0.161	0.221
-0.023	-0.161	0.222
-0.016	-0.160	0.222
-0.008	-0.160	0.221
0.000	-0.162	0.221
0.008	-0.161	0.221
0.016	-0.159	0.221
0.023	-0.164	0.221
0.031	-0.152	0.221
0.039	-0.175	0.222
0.047	-0.131	0.222
0.055	-0.201	0.225
0.063	-0.087	0.223
0.070	-0.259	0.227
0.078	0.026	0.228
0.086	-0.653	0.231
0.094	-2.244	0.234
0.102	-1.735	0.048
0.109	-1.681	-0.170
0.117	-1.602	-0.441
0.125	-1.540	-0.528
0.133	-1.060	-0.526
0.141	-1.184	-0.532
0.148	-0.748	-0.555
0.156	0.084	-1.128
0.164	0.003	-1.833
0.172	-0.627	-2.128
0.180	-0.747	-1.958
0.188	-0.395	-1.397
0.195	-0.633	-1.149
0.203	-0.991	-0.816
0.211	-1.337	-0.431
0.219	-1.586	-0.425
0.227	-1.457	-0.023
0.234	-1.370	0.027
0.242	-1.376	-0.354
0.250	-1.148	-0.676
0.258	-1.216	-0.841
0.266	-1.076	-0.871
0.273	-0.866	-0.972
0.281	-0.812	-1.101
0.289	-0.196	-1.125

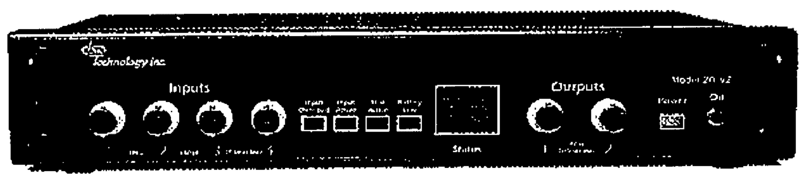
0.297	-0.149	-1.424	0.297	0.253	-1.215	0.297	0.175	-0.908
0.305	0.347	-1.118	0.305	1.059	-0.779	0.305	0.661	-0.580
0.313	1.117	-0.724	0.313	1.793	-0.121	0.313	1.845	-0.040
0.320	2.436	-0.134	0.320	3.993	0.765	0.320	3.574	0.819
0.328	4.327	0.704	0.328	6.239	1.407	0.328	6.041	1.530
0.336	6.173	1.488	0.336	6.907	2.052	0.336	7.213	2.188
0.344	6.909	2.211	0.344	5.640	2.810	0.344	6.117	2.915
0.352	5.059	2.967	0.352	2.706	3.848	0.352	3.119	3.988
0.359	2.277	3.964	0.359	0.056	4.286	0.359	0.312	4.479
0.367	0.044	4.141	0.367	-1.296	4.127	0.367	-1.287	4.612
0.375	-1.321	3.955	0.375	-1.473	3.600	0.375	-1.454	4.103
0.383	-1.392	3.531	0.383	-1.817	2.721	0.383	-1.859	3.106
0.391	-1.751	2.701	0.391	-1.705	2.219	0.391	-1.891	2.517
0.398	-1.569	2.138	0.398	-1.126	1.738	0.398	-1.229	2.052
0.406	-0.887	1.853	0.406	-0.102	1.468	0.406	-0.166	1.817
0.414	-0.056	1.514	0.414	0.631	0.917	0.414	0.541	1.209
0.422	0.510	0.947	0.422	0.513	0.154	0.422	0.465	0.383
0.430	0.489	0.177	0.430	0.427	-0.348	0.430	0.508	-0.140
0.438	0.476	-0.302	0.438	0.236	-0.329	0.438	0.254	-0.163
0.445	-0.054	-0.387	0.445	0.141	0.006	0.445	0.089	0.162
0.453	-0.430	-0.065	0.453	-0.596	0.172	0.453	-0.408	0.389
0.461	-0.194	0.043	0.461	-0.196	0.112	0.461	-0.410	0.433
0.469	-0.314	0.194	0.469	0.012	-0.126	0.469	0.061	0.125
0.477	-0.078	0.166	0.477	-0.276	-0.011	0.477	-0.294	0.216
0.484	-0.402	-0.044	0.484	-0.843	0.079	0.484	-0.826	0.267
0.492	-0.697	0.088	0.492	-0.845	-0.080	0.492	-0.588	0.175
0.500	-0.270	0.041	0.500	-0.133	-0.069	0.500	-0.329	0.163
0.508	-0.474	-0.048	0.508	-0.404	-0.092	0.508	-0.427	0.134
0.516	-0.302	-0.047	0.516	-0.360	-0.259	0.516	-0.318	0.035
0.523	-0.320	-0.071	0.523	-0.182	-0.204	0.523	-0.195	0.026
0.531	-0.266	-0.180	0.531	-0.347	-0.220	0.531	-0.227	0.014
0.539	-0.059	-0.250	0.539	-0.001	-0.233	0.539	-0.036	0.009
0.547	-0.162	-0.370	0.547	0.000	-0.263	0.547	0.002	-0.036
0.555	-0.176	-0.443	0.555	-0.118	-0.256	0.555	-0.133	-0.012
0.563	-0.012	-0.273	0.563	-0.013	-0.171	0.563	0.047	0.061
0.570	-0.032	-0.139	0.570	-0.127	-0.040	0.570	-0.134	0.195
0.578	-0.200	0.099	0.578	0.001	0.020	0.578	-0.078	0.272
0.586	-0.025	0.084	0.586	-0.039	-0.022	0.586	-0.093	0.201
0.594	0.003	-0.095	0.594	-0.148	0.026	0.594	-0.135	0.247
0.602	-0.023	-0.019	0.602	-0.117	-0.036	0.602	-0.104	0.236
0.609	-0.167	-0.074	0.609	-0.272	-0.172	0.609	-0.220	0.092
0.617	-0.253	-0.235	0.617	-0.315	-0.226	0.617	-0.374	0.020
0.625	-0.281	-0.279	0.625	-0.119	-0.214	0.625	-0.137	-0.006
0.633	-0.274	-0.350	0.633	-0.151	-0.101	0.633	0.040	0.124
0.641	0.014	-0.219	0.641	-0.535	-0.131	0.641	-0.496	0.140
0.648	-0.368	-0.136	0.648	-0.397	-0.123	0.648	-0.612	0.121
0.656	-0.606	-0.089	0.656	0.301	-0.099	0.656	0.234	0.125
0.664	0.041	-0.118	0.664	0.288	-0.268	0.664	0.377	-0.036

0.672	0.406	-0.288	0.672	-0.222	-0.256	0.672	-0.131	-0.030
0.680	-0.067	-0.290	0.680	-0.292	-0.252	0.680	-0.399	0.002
0.688	-0.230	-0.262	0.688	-0.585	-0.219	0.688	-0.705	0.010
0.695	-0.593	-0.244	0.695	0.076	-0.242	0.695	0.094	0.020
0.703	-0.274	-0.312	0.703	-0.102	-0.090	0.703	-0.023	0.113
0.711	0.109	-0.230	0.711	-0.615	-0.120	0.711	-0.450	0.104
0.719	-0.421	-0.111	0.719	-0.070	-0.137	0.719	-0.104	0.136
0.727	-0.121	-0.161	0.727	-0.102	-0.145	0.727	-0.233	0.103
0.734	-0.045	-0.189	0.734	0.063	-0.220	0.734	0.070	0.025
0.742	-0.082	-0.176	0.742	-0.105	-0.185	0.742	-0.009	0.061
0.750	0.054	-0.247	0.750	-0.495	-0.054	0.750	-0.430	0.183
0.758	-0.296	-0.158	0.758	-0.117	-0.062	0.758	-0.196	0.172
0.766	-0.327	-0.085	0.766	0.004	-0.099	0.766	-0.113	0.132
0.773	-0.209	-0.121	0.773	-0.048	-0.138	0.773	0.005	0.084
0.781	-0.140	-0.162	0.781	-0.302	-0.128	0.781	-0.188	0.090
0.789	-0.349	-0.150	0.789	-0.444	-0.089	0.789	-0.511	0.127
0.797	-0.352	-0.107	0.797	-0.056	-0.112	0.797	-0.120	0.124
0.805	-0.115	-0.112	0.805	-0.102	-0.097	0.805	-0.040	0.147
0.813	-0.106	-0.088	0.813	-0.239	-0.054	0.813	-0.183	0.212
0.820	-0.127	0.035	0.820	-0.373	-0.005	0.820	-0.342	0.245
0.828	-0.211	0.147	0.828	-0.162	0.019	0.828	-0.337	0.257
0.836	-0.171	0.124	0.836	0.068	0.036	0.836	0.046	0.262
0.844	-0.042	0.136	0.844	-0.159	0.095	0.844	-0.055	0.318
0.852	-0.063	0.151	0.852	-0.264	0.117	0.852	-0.259	0.345
0.859	-0.177	0.089	0.859	-0.162	0.098	0.859	-0.241	0.326
0.867	-0.146	0.056	0.867	0.057	0.099	0.867	-0.007	0.334
0.875	-0.068	0.032	0.875	-0.042	0.032	0.875	0.125	0.300
0.883	-0.110	0.005	0.883	-0.307	-0.046	0.883	-0.251	0.230
0.891	-0.166	-0.016	0.891	-0.217	-0.046	0.891	-0.277	0.212

Appendix D

(Equipment Specification and Calibration)

SigLab
Version 2.13



dsp Technology Inc.

Signal Analysis Group

48500 Kato Road, Fremont, CA 94538-7385 Tel: 510/657-7555 Fax: 510/657-7576
Email: siglab@dspt.com

Appendix F Hardware/Firmware Specifications

Input Characteristics

Number of channels:	4 (SigLab 20-42) or 2 (SigLab 20-22A and SigLab 20-22)
Type:	Differential
Impedance:	1 Meg Ω ||< 50 pF, Low side to ground is factory configured to 500 Ω. This resistor is easily changed.
CMRR:	> 60 dB from DC to 4 kHz > 60 - 20 • log(f/4 kHz) dB from 4 kHz to 20 kHz
Noise floor:	< - 140 dBVrms $\sqrt{Hz}$ from 500 Hz to 20 kHz < - 128 dBVrms $\sqrt{Hz}$ from 1.25 Hz to 500 Hz
Input bias current:	< 15 nA at 25°C
Protection:	30 Vrms (differential)
Voltage ranges:	10 ranges: ± 20 mV to ±10 V full scale in 6 dB steps
Coupling:	DC/AC (0.25 Hz AC -3 dB point)
User dc offset:	± 10 V on 10 V and 5 V input ranges ± 2.5 V on all other ranges
Residual dc offset:	DC coupled: ± 1 mV ± 0.02% of range + offset drift AC coupled: ± 2 mV ± 0.03% of range + offset drift
dc offset drift:	± 200 µV/°C on 5 V and 10 V input ranges ± 50 µV/°C on all other ranges (after calibration)
Absolute accuracy:	± 0.0025% of full scale range ± [0.03 + 0.02 • (f/20kHz)] dB
Data converter:	20-bit sigma delta A/D (SigLab 20-42 and SigLab 20-22A) 18-bit sigma delta A/D (SigLab 20-22)
Signal conditioning:	Interface for optional circuit board for customization
Bandwidths:	2 Hz to 20 kHz in a 1, 2, 5 sequence
Sampling rate:	2.56 times selected bandwidth
Alias protection:	> 90 dB alias protection (SigLab 20-42 and SigLab 20-22A) > 80 dB alias protection (SigLab 20-22) Implemented on all frequency ranges with fixed analog and programmable digital filters
Digital filters:	Real-time decimating and frequency translating digital filters Frequency translation center frequency resolution < 200 µHz
Filter efficiency:	The alias filters provide full 80 dB protection over 78% of the Nyquist bandwidth (equivalent filter roll off: >142 dB/octave)

Digital filter ripple:	< ± 0.02 dB (includes internal A/D digital filter)
Analog filter ripple:	< ± [0.01 + 0.02 • (f/20 kHz)] dB
Gain match:	< [0.01 + 0.03 • (f/20 kHz)] dB
Phase match:	Between channels 1 and 2 or 3 and 4, Same gain range: < [0.1 + 0.9 • (f/20 kHz)]° Different gain ranges: < [0.2 + 3.0 • (f/20 kHz)]°
Dynamic range:	All harmonic, intermodulation, and spurious signals will be: > 84 dB below full scale on 20, 40 and 80 mV ranges > 90 dB below full scale on all other input ranges
Transfer function dynamic range:	Greater than 110 dB isolation, DC-20 kHz (reference = channel 1)
Overload detectors:	On both low and high side of differential inputs and at the A/D input
Trigger sources:	Input channels, output channels, external TTL
Trigger threshold:	17 steps from -71% to 71% of full scale (9% steps)
Trigger slope:	Positive or negative
Trigger hysteresis:	Selectable, 9% or 18% of full scale
Transient response:	Overshoot/preshoot <15% on 20 kHz bandwidth or with digital filters off. Otherwise <22%
Sampling rate:	51.2 kHz max per channel (simultaneous sampling)
Frequency accuracy:	± 0.01% with internal timebase; an external timebase input is available via rear panel connector.

Output Characteristics

Number of channels:	2
Type:	Single ended
Impedance:	51 Ω, ±1%
Noise floor:	< -130 dBVrms $\sqrt{Hz}$ from 500 Hz to 20 kHz < -100 dBVrms $\sqrt{Hz}$ from 5 Hz to 500 Hz
Drive current:	20 mA rms
Protection:	15 Vrms
Maximum level:	± 10 V (including dc offset)
Level control:	20 mV to 10 V with better than 1 mV resolution
User dc offset:	± 10 V with < 1 mV resolution
Residual dc offset	± 4 mV + offset drift
dc offset drift:	± 200 µV/°C (after calibration)
Amplitude accuracy:	± 2 mVrms ± [0.09 + 0.12 • f/20 kHz)] dB
Crosstalk:	> 100 dB channel-channel isolation
Data converter:	18-bit sigma delta D/A, integrated smoothing filter
Filter ripple:	< [0.03 + 0.12 • (f/20 kHz)] dB
Spectral purity:	Harmonics, subharmonics, intermodulation products and spurious signals are below the selected output level (in Vrms) by the lesser of: [93-Vpk-(f/1.0 kHz)] dB or 90 dB. The table below gives some examples. (For low level outputs the noise floor must be considered.)

General

Host Interface:	SCSI with selectable active terminator, high density connectors
Power requirements:	12 VDC (15 max), less than 1.5 Amps (SigLab 20-42) or 1.3 Amps (SigLab 20-22A and SigLab 20-22)
ac adapter:	Input: 95-240 VAC, Output: 12 VDC
Internal battery:	7.2 V, 1500 mAh
Data memory:	Standard: 1 MB (SigLab 20-22) or 4 MB(SigLab 20-42 and SigLab 20-22A). 4, 8, 16, and 32 MB options
Size:	Aluminum case, 8.5" x 11" x 2" (21.6 cm x 27.9 cm x 5.1 cm)
Weight:	4.5 lbs. (2 kg) includes internal battery

Due to our dedication to continuous improvement, specifications are subject to change.

	Output Frequency		
Level	2 kHz	4 kHz	6 kHz
1 Vpeak	-90 dB	-87 dB	-85 dB
6 Vpeak	-85 dB	-83 dB	-81 dB

Certificate of Calibration

This document certifies that the equipment referenced below meets published specifications. The calibration procedure is in compliance with ISO 10012-1, and former MIL-STD-45662A and is traceable to NIST.

Model Number:	480E09	N.I.S.T Project #:	6720012
Serial Number:	24355	Calibration Date:	12/19/2000
Description:	Signal Conditioner	Recalibration Date:	
Test Procedure:	AT-103-3	Calibration Technician:	Chris Romeo CR

PCB PIEZOTRONICS

3425 Walden Avenue Depew, New York, USA 14043-2495

For any questions concerning this certificate, please call PCB at (716) 684-0001 and ask for an application engineer.

Certificate of Calibration

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Model Number:	480E09	N.I.S.T Project #:	6720012
Serial Number:	24356	Calibration Date:	12/19/2000
Description:	Signal Conditioner	Recalibration Date:	
Test Procedure:	AT-103-3	Calibration Technician:	Chris Romeo CR

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— Calibration Certificate —

Per ISA-RP37.2

Model No. Q353B33

Serial No. 64654

PO No. ______ Customer ______

Calibration traceable to NIST thru Project No. 822/262123-99

ICP® ACCELEROMETER
with built-in electronics

Calibration procedure is in compliance with ISO 10012-1, and former MIL-STD-45662A and traceable to NIST.

CALIBRATION DATA

Voltage Sensitivity	101.4	mV/g
Transverse Sensitivity	0.1	%
Resonant Frequency	26.0	kHz
Output Bias Level	9.7	V
Time Constant	≥10	s

KEY SPECIFICATIONS

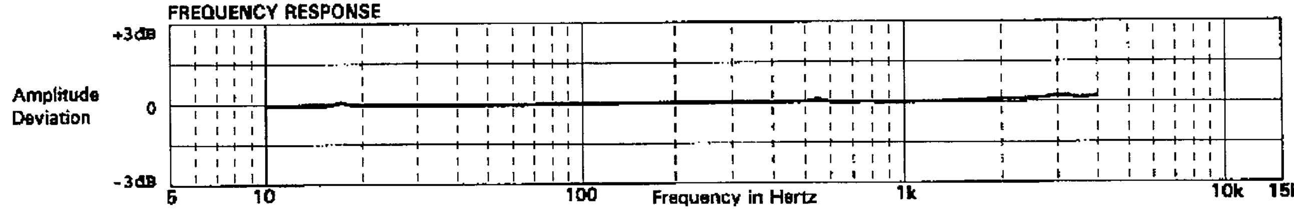
Range	50	±g
Resolution	0.0005	g
Temp. Range	-65/+250	°F

METRIC CONVERSIONS:
ms^{-2} = 0.102 g
°C = 5/9 x (°F - 32)

Reference Freq.

Frequency Hz		10	15	30	50	100	300	500	1000	3000	4000				
Amplitude Deviation %		-0.8	-1.1	-0.7	-0.5	0.0	0.3	0.4	0.0	2.8	2.4				

FREQUENCY RESPONSE



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716-684-0001

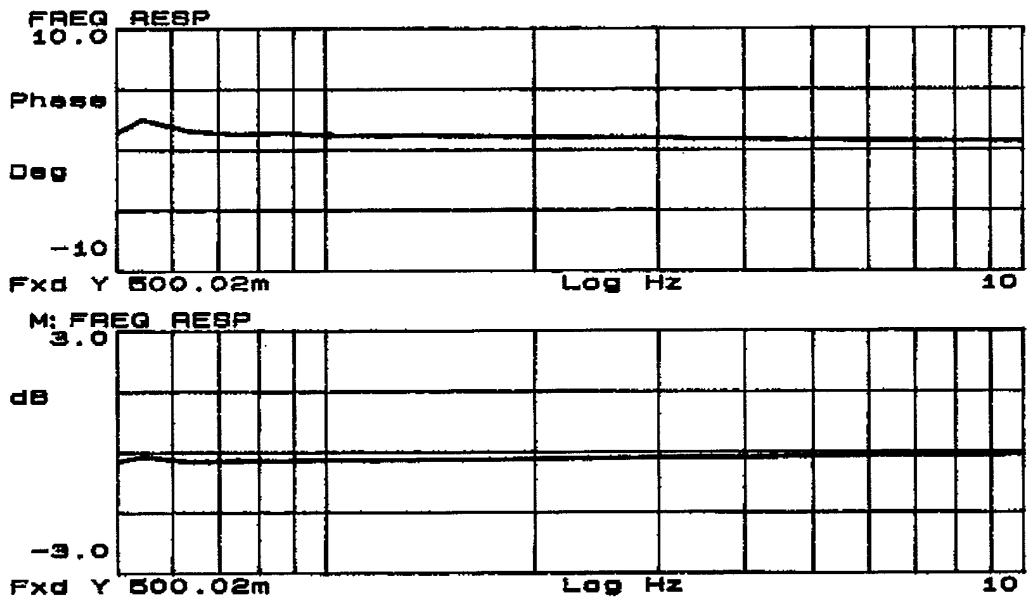
Calibrated by John Targia
Date 11-07-2000

Calibration Certificate

Model No.: Q353B33 Date: 11-07-2000

Serial No.: 64654 By: S. Skibniewski

* The Gravimetric Method of Calibration was used to provide this extended Frequency Response. This method specifically references mass and gravity which are standards of nature. The Frequency Response is referenced to the 10 Hz. data point shown on the Calibration Certificate containing the higher Frequencies.



Frequency (Hz.)	0.5	1.0	2.0	4.0	5.0	10
Deviation (%)	-2.5	-2.2	-2.0	-1.6	-1.3	-0.8

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-ISO 9001 Certified-

— Calibration Certificate —

Per ISA-RP37.2

Model No. 0353B33

Serial No. 69268

PO No. ______ Customer ______

Calibration traceable to NIST thru Project No. 822/262123-99

ICP®ACCELEROMETER
with built-in electronics

Calibration procedure is in compliance with ISO 10012-1, and former MIL-STD-45662A and traceable to NIST.

CALIBRATION DATA

Voltage Sensitivity	104.3	mV/g
Transverse Sensitivity	0.6	%
Resonant Frequency	26.0	kHz
Output Bias Level	8.4	V
Time Constant	≥10	s

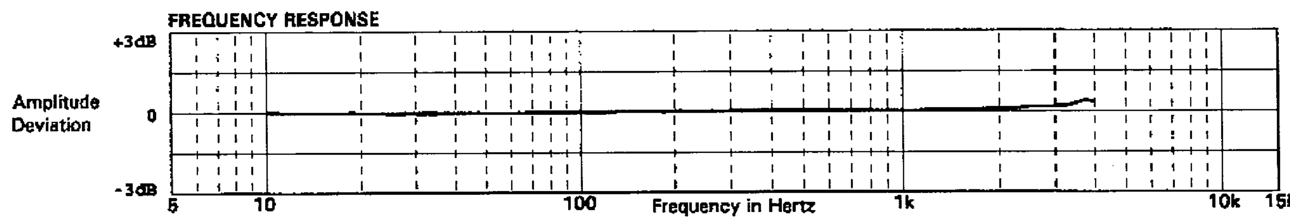
KEY SPECIFICATIONS

Range	50	±g
Resolution	0.0005	g
Temp. Range	-65/+250	°F

METRIC CONVERSIONS:
ms^{-2} = 0.102 g
°C = 5/9 x (°F - 32)

Reference Freq.

Frequency Hz		10	15	30	50	100	300	500	1000	3000	4000				
Amplitude Deviation %		-0.3	-0.4	-0.6	-0.4	0.0	0.3	0.4	0.1	2.1	3.6				



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716-684-0001

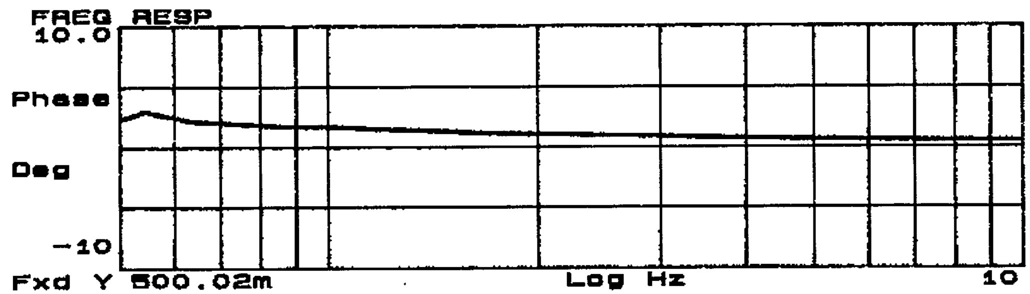
Calibrated by James Wasielewski JW
Date 10-16-2000

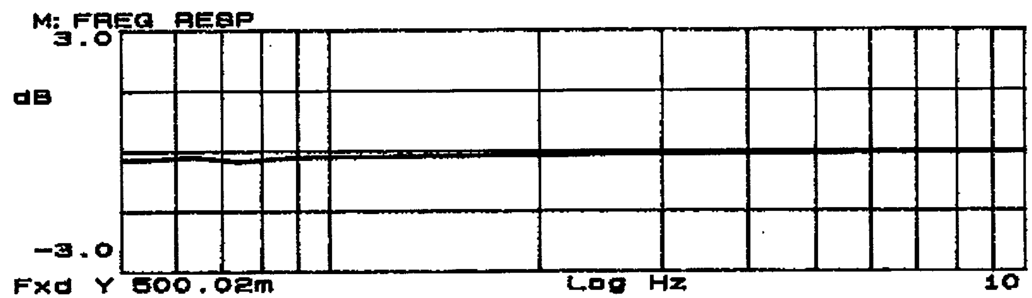
Calibration Certificate

Model No.: Q353B33 Date: 10-17-2000

Serial No.: 69268 By: S. Skibniewski

* The Gravimetric Method of Calibration was used to provide this extended Frequency Response. This method specifically references mass and gravity which are standards of nature. The Frequency Response is referenced to the 10 Hz. data point shown on the Calibration Certificate containing the higher Frequencies.





Frequency (Hz.)	0.5	1.0	2.0	4.0	5.0	10
Deviation (%)	-2.6	-1.6	-1.1	-0.7	-0.6	-0.3

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